AFML-TR-66-102

CREEP PROPERTIES AND CREEP MEASUREMENT TECHNIQUES FOR A CHROMIUM-MAGNESIUM OXIDE COMPOSITE UP TO 2200°F IN AIR

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TECHNICAL REPORT AFML-TR-66-102

JUNE 1966

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AIR FORCE MATERIALS LABORATORY
RESEARCH AND TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

NOTICES

1300 - July 1966 - 773-50-1137

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FOREWORD

This report was prepared by Sidney O. Davis and David C. Watson of the Materials Information Branch, Materials Applications Division, Wright-Patterson Air Force Base, Ohio. This program was conducted under Project No. 7381, "Materials Applications," Task No. 738106, "Design Information Development." This report covers work conducted from March 1963 to July 1964. The manuscript was released by the authors in November 1965 for publication as an RTD Technical Report.

The testing was done by the Materials Information Branch, Materials Applications Division, Air Force Materials Laboratory.

The authors would like to express their appreciation to Mr. Roger Niemi of the Monsanto Research Corporation (Dayton Laboratory) for his support and assistance in the metallographic work.

It is also a pleasure to acknowledge the work in preparing this report done by Capt. James H. Frye, an Air Force Reserve Officer.

All (or many) of the items compared in this report were commercial items that were not developed or manufactured to meet any Government specification, to withstand the tests to which they were subjected, or to operate as applied during this study. Any failure to meet the objectives of this study is no reflection on any of the commercial items discussed herein or on any manufacturer.

This technical report has been reviewed and is approved.

D. A. SHINN
Chief, Materials Information Branch
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ABSTRACT

A test program was conducted to obtain creep rupture properties of a chromium-magnesium oxide composite alloy, Chrome-30 (93.5 percent chromium, 0.5 percent titanium, 6.0 percent magnesium oxide), at elevated temperature in an air environment. Four series of creep rupture tests were conducted at temperatures of 1700°, 1850°, 2000°, and 2200°F with stresses applied ranging from 1000 to 10,000 psi using a constant load machine. The material was in the form of 0.047 inch thick sheet.

In addition to the creep rupture properties, a detailed description of the test equipment and testing procedure is presented. Photomicrographs are included to describe the general microstructure.

Also included is a discussion of the correlation of total deformation versus time at elevated temperatures using two measuring methods, drawhead movement versus extensometer measurements. The test data revealed that there can be as much as 65 percent error in total deformation reported when measuring creep using drawhead movement of the creep frame instead of using an extensometer fastened firmly to the gage section.

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SECTION I

INTRODUCTION

Cobalt and nickel-base alloys are limited to a maximum temperature for useful strength* in the range of 1550° to 1950°F, and refractory metals must be coated to be used at elevated temperatures in an oxidizing atmosphere. Chromium, with its inherent oxidation resistance, relatively high melting point, and moderate density, seems a logical material for use at temperatures above 2000°F. However, the use of chromium as a structural material has been retarded due to its high susceptibility to nitrogen absorption upon exposure to high temperature in air, which results in a high ductile-brittle transition temperature.

Chrome-30 (Reference 1), a chromium-magnesium oxide composite developed by the Bendix Corporation, has shown promising properties and is available as a sheet product. The properties of this material include: (1) a ductile-brittle transition below room temperature (45°F for recrystallized sheet); (2) good oxidation and scaling resistance up to 2400°F; a resistance to nitrogen embrittlement up to 2400°F; resistance to erosion; and a usable strength for some high temperature applications (4400 psi yield strength at 2200°F for recrystallized sheet). Potential applications include high-temperature jet engine components, heat shielding for space vehicles, high-temperature furnace hardware, and components in air breathing nuclear reactors (Reference 2).

This report describes the test procedures and equipment used in the test program of Chrome-30 and presents creep data in both tabular and graphical form. The test data include: (1) percent creep deformation versus time at selected temperatures with varying stress; and (2) stress rupture properties for selected stress-temperature conditions. This information supplements the data previously reported in the technical documentary report ASD-TDR-63-297.

Also included in this report are limited tests comparing deformation derived from drawhead movement versus extensometer readings.

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*The ability to withstand 10,000 psi for 100 hours (Reference 6)

SECTION II

MATERIAL, PROCESSING, AND SPECIMEN FABRICATION HISTORY

Specimens for this test program were prepared by the Bendix Products Aerospace Division of the Bendix Corporation from 14 selected sheets, under Contract AF 33(657)-8422 (Reference 1). The sheet identification numbers were 203, 208, 212 to 214, and 215 to 224. According to the producer the nominal weight percent composition of the blended composite was 93.5 percent electrolytic chromium, 0.5 percent titanium, and 6.0 percent magnesium oxide. Typical impurity levels of the chromium powder blend were as follows:

Impurity Element	O_2	N_2	H_2	Fe	S	C
Impurity Level (ppm)	6600	30	210	590	260	150

The sheets were processed using the following warm rolling procedure (Reference 1) for producing the lowest ductile-to-brittle transition in the finished sheet:

Warm Rolling Temperature	- 900°F
Total Reduction	- 40 to 44 percent
Reduction per Pass	- 6.5 to 8 percent
Number of Passes	- 7
Final Rolling Direction	- Parallel to hot rolling direction
Final Thickness	- 0.049 inches

The final annealed processing of the sheets was accomplished in vacuum for a total time of one hour at 1800°F.

The creep rupture test specimens (Figure 1) were cut from the warm-rolled sheets transverse to the rolling direction. Final sizing of the specimens was accomplished by stack grinding in a contoured fixture. This stack grinding technique resulted in a variable gage width ranging from 0.201 to 0.221 at the minimum reduced section, depending upon specimen location in the stack. Although the width varied, the contoured fixture was designed so as to ensure accurate centering of the 3/8 inch diameter holes on the reduced section centerline.

All specimens were then electropolished to remove one mil of material per surface by immersion in a bath consisting of ten parts glacial acetic acid and one part 60 percent CP perchloric acid for approximately four minutes. The bath was operated at 110° to 125°F, 21 volts, and 3 amps per square inch. The final examination of the specimens was made with dye penetrant under a 15X microscope.

SECTION III

TEST EQUIPMENT AND PROCEDURES

1. TEMPERATURE MEASUREMENT AND CONTROL

a. Creep Rupture Tests

The creep rupture tests were performed at four temperature levels (1700°, 1850°, 2000°, and 2200°F). For tests which were conducted at the first three named temperatures, the test specimens were heated by means of an Arcweld Model F-8 power positioning furnace (Figure 2). The following types of temperature recording-controlling equipment were used: (1) a Barber-Colman Model 200-00170 temperature recorder-controller, which was used to control the specimen temperature, and (2) a Leeds and Northrup (L&N) Speedomax Type G temperature indicator (Figure 2). The recorder-controller had a controlling accuracy of 1/4 of one percent full scale range, a full scale range equal to 2500°F, and smallest divisions of 10°F on the indicating scale. The L&N temperature indicator also had an indicating scale with divisions of 10°F.

The test temperatures of 2000°F and less were measured and controlled using chromel-P, alumel thermocouples. The thermocouples were made from coils of Chromel-P and alumel wire. The coils were calibrated using standard emf versus National Bureau of Standards No. 27 platinum wire. One thermocouple was attached to each end of the specimen gage length by wiring the thermocouple bead to the specimen surface. These two thermocouples were used to check temperature uniformity at the top and bottom of the gage length. A third thermocouple was attached to the center of the gage length and was used to control temperature during the tests. This was done by transmitting the emf generated millivolt signal from the thermocouple to the temperature recorder-controller, and in turn the power input to the furnace was controlled proportionately based on a fixed-point setting on the temperature recorder-controller. A schematic diagram illustrating this heating system is shown in Figure 6.

For the series of tests conducted at 2200°F, a different method of heat application was required because of the 2000°F limitation of the Inconel 713 nickel-base superalloy pull rods and grips' material. These tests were performed using an induction heating coil in conjunction with an induction heating unit utilizing a 450 kc frequency generator with an output power of 7.5 kw (Figure 3). The induction heating coil restricted the 2200°F temperature to the specimen, and the pull rods remained sufficiently below this figure to permit operation below their 2000°F temperature limitation.

Thermocouple measurement of specimen temperature was erratic when using induction heating methods due to the voltage induced in the thermocouple wires themselves. For the induction heating method used in the tests at 2200°F, the test temperature was measured using an optical brightness pyrometer. An L&N optical brightness pyrometer, Serial No. 1611891, with the smallest divisions of 10°F on the indicating scale was used to obtain temperature readings. This pyrometer was calibrated by the National Bureau of Standards, Test No. 175286. To determine the true temperature of the surface of a specimen using a brightness pyrometer, the emittance must be known. Bendix Products Aerospace Division reported an emittance of 0.85 for Chrome-30 in air at 1200°F and above (Reference 3). However, the wavelength at which this was obtained was not given. Therefore, a specimen with a diameter of 15/16 inch and 1/4 inch thick was made from Chrome-30 and the surface was finisned using 150 grit emery cloth. A chromel-P, alumel thermocouple from the calibrated coils was wired to the specimen with the thermocouple bead embedded in a small hole in the specimen. The specimen was placed in an Arcweld Model F-8 furnace, and temperature readings were taken using both the millivolt

signal from the thermocouple and the reading from the optical brightness pyrometer in the temperature range of 2000° to 2400°F. Using this data (pyrometer versus thermocouple temperature readings) the optical brightness pyrometer test temperature for a true temperature of 2200°F was manually controlled by adjusting the output of the induction heating unit as a function of time.

An attempt was made to automatically control the specimen true temperature of 2200°F by transmitting the feedback signal from a two-color pyrometer through a pyrometer temperature indicator to a temperature recorder-controller. In turn, the output power of the induction heater could be controlled (Figure 3). However, this could not be done because the distance between the turns of the induction coils required to obtain a constant temperature over the gage length, would not permit a sufficient field of view for the pyrometer. A steel inclosure (Figure 3), coated on the inside with a ceramic material, was placed around the induction coil and specimen to shield this assembly from air drafts. However, this inclosure was too troublesome and it was abandoned.

The short axial length requirement of the induction heating coil, because of the limiting temperature capabilities of the pull rods and grips, proved to be a limiting factor in conducting the 2200°F tests. As the specimens elongated under load, it became impossible to maintain the specified 2200°F temperature uniform along the gage length. As a result, it was necessary to discontinue these tests prior to rupture.

In most tests, temperature readings along the reduced section of the specimens 1 1/4-inch gage length were held to an indicated ±5°F from the nominal test temperature.

b. Correlation Tests

For the strain measurement technique comparison phase of this reported work, the procedure of using thermocouples for measurement and control of temperature was the same as reported in the creep rupture test section for test temperatures of 2000°F and less. The temperature readings along the one inch gage length of the specimen were held to an indicated ±5°F from the nominal test temperature.

An Arcweld Model F -6 power positioning furnace was used in conjunction with an L & N Speedomax Type H temperature recorder-controller for the comparison tests (Figure 5). This recorder-controller had a controlling accuracy of 1/4 of one percent full scale range, a full scale range of 2500°F, and divisions on the indicating scale of 10°F. The material of the pull rods in the hot zone of the furnace was Inconel-X, a nickel base superalloy capable of 1800°F testing temperature.

2. STRAIN MEASUREMENT

a. Creep Rupture Tests

The elevated temperatures involved did not allow deformation measurement with an extensometer fastened to the gage section because of temperature limitations of the construction material of the extensometer. As a consequence, the elongation of the specimen was determined by measuring the movement of the lower pull rod (Figure 4). Deformation of the test specimen of which creep data are tabulated and plotted in this report was measured using the output of a Daytronic Model 102B600 linear differential transformer on the direct loading creep frame (Figures 2 and 4). This deformation output was fed through an Arcweld Model 200 exciter demodulator and recorded on a Wheelco Model 8006-2500 recorder (Figure 2). The spring in the linear differential transformer put a force on the bolt and thus caused a bending moment. As a consequence, two slotted flat specimen adapters (Figure 4) were used in the load linkage so that the specimen would not "see" this bending moment. A General Electric Model 8KT8D2 time meter (Figure 2) was used as a second time reference check on the time axis accuracy of the Wheelco recorder.

b. Correlation Tests

Two tests were performed for the correlation of strain measurement techniques and were conducted at two different temperatures and stresses. Two methods of measuring deformation were employed: (1) drawhead movement of the creep frame, and (2) extensometer movement fastened directly to the gage section of the specimen.

The measuring method utilized on the test specimen gage length inside the furnace (Figure 5) consisted of an Arcweld Model 205 extensometer having a temperature limitation of 1800°F. This creep testing limitation temperature in the hot zone of the furnace was imposed by the maximum allowable 1800°F temperature exposure of the Inconel-X grips and extensometer.

The deformation measured utilizing the two methods employed in these correlation tests was compared using the output from two Arcweld Model 9234-K linear differential variable transformers, LDVT, (Figure 5). One LDVT was located on the drawhead of the creep machine and the other on the test specimen gage length extensometer as shown in Figure 5. The outputs were fed through demodulators marketed by Automatic Timing and Controls Incorporated (Type 6101 F-2-X), and recorded on a Wheelco recorder.

3. TESTING PROCEDURE

a. Creep Rupture Tests

The creep rupture tests were performed using a direct loading type of creep frame (Figures 2 and 3) at the following four temperature levels: 1700°, 1850°, 2000°, and 2200°F. A Toledo scale, which can measure to 0.01 lbs, was used to check the loading weights in these tests.

In conducting the creep rupture tests, the temperature was raised to the desired level after which the specimen was allowed to soak for approximately one-half hour prior to loading.

During the period of increasing temperature and for the one-half hour soak time, the load linkage connecting pin (Figure 4) was removed and the load platform was supported by means of a hydraulic jack. After the specimen had soaked for the specified time, the load platform was raised so that the connecting pin would go freely into its hole. At this time the connecting pin was placed in the hole and the deformation recorder was zeroed through the linear differential transformer (Figure 4). Then the deformation recorder was started and the load platform was lowered gradually to apply the load. The hydraulic jack was lowered an additional amount sufficient to allow for specimen deformation prior to failure. Upon failure of the specimen, the load platform dropped, depressing a limit switch mounted in the jack platform, and the furnace and all recording equipment were shut off automatically.

b. Correlation Tests

A lever-arm-operated dead weight creep frame, Arcweld Model D, with a 5 to 1 lever arm ratio, was utilized for the strain measurement technique comparison phase of this reported work. This creep frame has an automatic elongation take-up through the use of a screw type precision way drawhead (Figure 5).

In conducting the correlation tests, the following procedure was followed in setting up the tests:

(1) The extensometer was fastened firmly to a one inch gage section of the specimen.

(2) The specimen, extensometer, and hot grip assembly was placed in the furnace and attached to the cold grip couplings on the creep frame (Figure 5).

(3) The "automatic inch down" mechanism was engaged and the drawhead was allowed to level the lever arm.

(4) The two linear differential transformers (Figure 5) were plugged into the strain recording unit, calibrated by using the micrometer and demodulator, and were "zeroed" (Figure 5).

(5) The furnace was turned on, and the temperature of the specimen was allowed to stabilize and soak for one-half hour at the desired temperature.

(6) Elongation due to thermal expansion was zeroed out on the strain recorder using the micrometer on the extensometer and the bolt on the drawhead (Figure 5).

(7) After the proper amount of weights for the test were applied on the weight pan, these weights were slowly released by lowering the weight car.

SECTION IV

DISCUSSION OF RESULTS

The method of deformation measurement used in the creep rupture tests (measuring movement of the lower load linkage) includes deformation in the reduced gage section, the specimen fillets, and any slight deformation of the linkage system as shown in Figure 4. Calculation of the creep deformation was made by a method similar to that used by Thomas and Carlson (Reference 4), and from which an average effective gage length from the experimental creep data was obtained in the correlation tests (Figure 16 and Tables 6 and 7).

The results of two tests for the correlation of strain measurement techniques are presented in Table 6 and Figure 16. The data (Figure 16) is presented as total deformation versus time. Total deformation is defined as meaning all strain generated from the moment a test specimen is loaded and includes elastic, initial plastic, and subsequent creep strain. From each test there were obtained two curves on the deformation recorder, one curve from the extensometer fastened to a one inch gage section, and a second curve from the drawhead movement, which was used to indicate the deformation in the sample between the loading pins and in the linkage system. The recorder curve from the drawhead movement showed that the drawhead leveled the lever arm for each 0.002 to 0.003 inch deflection in the specimen and load linkage. The ratio of the total deformation of the drawhead movement to the unit deformation from the extensometer is the effective gage length (Table 7). The average effective gage length (Table 7) was used to determine the percent creep deformation (Figure 7 through 12) in the creep rupture tests.

The results of the creep rupture tests on Chrome-30 at elevated temperatures are presented in Tables 1 through 5 and Figures 7 through 15. Figures 7 through 9 show percent creep deformation to 2.8 percent. Figures 10 through 12 show percent creep deformation to 28 percent. These data are presented as percent creep deformation versus time. Creep deformation recorded in this report includes only the time-dependent strain generated after a specimen has been stressed and does not include the initial elastic-plastic deformation. The stress rupture curves, stress versus failure time, at the selected temperatures, are shown on Figure 14.

It should be realized that there is possible error in the data and this should be taken into consideration when using this data. The average effective gage length (Table 7) was obtained from tests at 1700° and 1800°F. This average effective gage length was then applied to the creep data obtained at temperatures of 1700°, 1850°, and 2000°F. Differences in effective gage length can exist for a given alloy and specimen over a temperature range of testing simply due to a steeper stress-creep rate curve with increasing temperature (Reference 4). The plot of stress versus minimum creep rate (Figure 15) shows nearly parallel straight lines with a discontinuity in the 1700°F curve. The stress-creep rate curves increase in slope with increasing temperature. Also, in the progress of a single creep test (Table 7), there is a variation of the effective gage length.

However, if no attempt was made to obtain an effective gage length, there could have been considerable error in the reported data. The data in Figure 16 show a 65 percent error between the total deformation measured by drawhead movement and that measured by the extensometer at the gage length at 5 hours for the test at 1000 psi and 1800°F, and at 3 hours for the test at 5000 psi and 1700°F.

Because of the different heating method used to obtain the 2200°F testing temperature, the average effective gage length (Table 7) was not applied to the 2200°F creep data. The temperature, outside the reduced section, in the specimen fillets and holder system was

considerably less than 2200°F, and it was assumed that the significant creep deformation occurred in the reduced gage length, 1-1/4 inches, of the specimen. Therefore the 2200°F data (Table 4 and Figure 13) is presented as creep deformation versus time based upon an effective gage length of 1-1/4 inches.

To permit analysis of the microstructure, photomicrographs (Figures 17 through 21) of a selected group of test specimens were made by the Monsanto Research Corporation (Dayton Laboratory). Figure 17 shows the microstructure of a typical test specimen in the as-received condition. The magnesium oxide (MgO) dispersions, which are dark, are dispersed in the chromium matrix. As the testing temperatures increased, the MgO particles and the matrix grains increased in size. At the higher testing temperatures, for example 2000°F (Figure 21), the MgO particles appear to have gray areas around them. NASA has reported these gray areas as being $MgCr_2O_4$ (Reference 5).

SECTION V

CONCLUSIONS

The test data showed that the Chrome-30 alloy can be used only at low tensile stresses and for short time applications at elevated temperatures of 1700°F and above. For example, the following times and temperatures were required for 0.5 percent creep at 2000 psi: 42 hours at 1700°F, 3.1 hours at 1850°F, and 32 minutes at 2000°F.

The test data revealed that there can be as much as a 65 percent error in total deformation reported when measuring creep using drawhead movement of the creep frame without correction instead of using an extensometer fastened firmly to the gage length section. Overly conservative design stresses will result when creep resistance is used as a design requirement if design creep data is determined by drawhead movement.

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4. Thomas, J. M., and Carlson, J. F., "Errors in Deformation Measurements for Elevated Temperature Tension Tests." ASTM Bulletin, May 1955, pp. TP95-TP99.

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TABLE I

CHROME-30 DEFORMATION-TIME DATA AT 1700 °F

CREEP DEFORMATION (%) E.G.L. = 1.65 in.

TIME (hours)	STRESS = 2000 psi *208-5
0.1	0.00
0.2	0.00
0.5	0.03
1.0	0.09
10.0	0.24
20.0	0.30
50.0	0.61
100.0	0.85
142.5	0.91(A)

TIME (hours)	STRESS = 4000 psi *208-6	*224-3	AVG.
0.1	0.00	0.18	0.09
0.2	0.00	0.21	0.10
0.5	0.12	0.36	0.24
1.0	0.24	0.48	0.36
2.0	0.30	0.52	0.41
5.0	0.36	0.79	0.58
10.0	0.61	0.85	0.73
20.0	0.67	1.09	0.88
50.0	1.45	1.39	1.42
100.0	2.36	2.73	2.54
200.0	4.61	5.03	4.82
235.4	—	6.30(B)	—
375.0	14.85	—	—
376.2	(C)	—	—

TIME (hours)	STRESS = 6000 psi *214-4	*214-6	AVG.
0.1	0.12	0.06	0.09
0.2	0.15	0.06	0.10
0.5	0.27	0.12	0.20
1.0	0.30	0.15	0.22
2.0	0.48	0.33	0.40
5.0	0.91	0.73	0.82
10.0	1.09	1.27	1.18
20.0	3.06	2.15	2.60
50.0	7.42	5.21	6.32
72.9	15.67(C)	—	—
96.7	—	17.70	—
96.8	—	(C)	—

TIME (hours)	STRESS = 8000 psi *214-1	*215-6	*218-6	AVG.
0.1	0.21	0.18	0.24	0.21
0.2	0.36	0.30	0.42	0.36
0.5	0.91	0.85	0.85	0.87
1.0	1.42	1.52	1.52	1.49
2.0	2.48	3.45	2.85	2.93
5.0	5.52	14.18	6.48	8.73
7.0	—	25.76(C)	—	—
10.0	11.58	—	14.73	13.16
13.0	—	—	22.06(C)	—
15.2	24.12(C)	—	—	—

TIME (hours)	STRESS = 10000 psi *214-5	*214-7	*216-1	AVG.
0.1	0.52	0.48	0.39	0.46
0.2	1.12	1.45	0.82	1.13
0.5	2.54	3.03	1.97	2.51
1.0	4.97	5.76	3.97	4.90
2.0	11.09	12.36	8.39	10.61
2.1	11.94(D)	—	—	—
3.0	—	25.82(C)	—	—
3.8	—	—	22.88(C)	—

LEGEND

(A) Test terminated in time indicated with no failure
(B) Test discontinued due to power failure
(C) Specimen ruptured in gage length
(D) Test discontinued due to control thermocouple failure
* Code numbers refer to sheet identification numbers.
E.G.L.—Effective gage length

TABLE II

CHROME-30 DEFORMATION-TIME DATA AT 1850°F

TIME (hours)	CREEP DEFORMATION (%) E.G.L. = 1.65 in.		
	STRESS = 2000 psi		
	*224-2	*222-6	AVG.
0.1	0.00	0.12	0.06
0.2	0.06	0.18	0.12
0.5	0.30	0.30	0.30
1.0	0.36	0.33	0.34
2.0	0.42	0.36	0.39
5.0	0.73	0.58	0.66
10.0	1.03	0.91	0.97
20.0	1.64	1.33	1.48
50.0	3.45	3.76	3.60
76.8	—	6.79(F)	—
100.0	8.36	—	—
120.0	12.91	—	—
150.0	27.15	—	—
163.2	35.27	—	—
450.0	(A)	—	—
	STRESS = 3000 psi		
	*222-7	*223-1	AVG.
0.1	0.30	0.18	0.24
0.2	0.42	0.24	0.33
0.5	0.61	0.36	0.48
1.0	0.85	0.61	0.73
2.0	1.15	0.85	1.00
5.0	1.82	1.15	1.48
10.0	2.73	1.88	2.30
20.0	5.15	3.76	4.45
36.6	22.42	—	—
40.0	32.06	20.24	26.15
41.2	36.06(E)	—	—
44.0	—	36.30 (E)	—
50.6	—	(C)	—
69.5	(C)	—	—

TIME (hours)	CREEP DEFORMATION (%) E.G.L. = 1.65 in.		
	STRESS = 4000 psi		
	*222-4	*222-5	AVG.
0.1	0.00	0.06	0.03
0.2	0.30	0.36	0.33
0.5	0.45	0.54	0.50
1.0	0.97	0.91	0.94
2.0	1.58	1.52	1.55
5.0	3.39	3.39	3.39
10.0	7.76	7.09	7.42
16.5	34.91 (C)	—	—
16.7	—	22.91 (C)	—
	STRESS = 6000 psi		
	*223-3	*223-5	AVG.
0.1	0.48	0.73	0.60
0.2	0.97	1.39	1.18
0.5	2.30	3.15	2.72
1.0	4.73	5.82	5.28
2.0	10.48	11.70	11.09
3.0	21.21	22.24	21.72
3.2	26.67 (C)	27.39	27.03
3.3	—	28.12 (C)	—
	STRESS = 8000 psi		
	*223-6	*223-7	
0.1	3.15	3.21	3.18
0.2	5.94	6.30	6.12
0.5	17.88	18.67	18.28
0.55	21.82	22.48	22.15
0.65	30.00 (C)	—	—
0.66	—	34.73 (C)	—

LEGEND

(A) Test terminated in time indicated with no failure
(C) Specimen ruptured in gage length
(E) Deformation exceeded the limits of the deformation recorder
(F) Test discontinued due to malfunction of temperature controller
* Code numbers refer to sheet identification numbers
E.G.L. — Effective gage length

TABLE III

CHROME-30 DEFORMATION-TIME DATA AT 2000°F

TIME (hours)	CREEP DEFORMATION (%) E.G.L. = 1.65 in.				
	STRESS = 1000 psi				
	*218-2	*218-3	*218-4	*218-5	AVG.
0.1	0.03	0.36	0.00	0.06	0.11
0.2	0.18	0.42	0.03	0.09	0.18
0.5	0.33	0.61	0.24	0.12	0.32
1.0	0.48	0.73	0.36	0.24	0.45
2.0	0.73	1.03	0.42	0.42	0.65
5.0	0.85	1.39	0.91	0.85	1.00
10.0	1.85	1.88	1.54	1.52	1.70
20.0	3.15	3.09	3.15	3.58	3.24
25.8	4.12 (B)	—	—	—	—
50.0	—	7.52	10.48	10.79	9.60
51.0	—	—	—	(G)	—
51.7	—	—	12.18 (A)	—	—
100.0	—	25.33	—	—	—
118.0	—	34.67 (E)	—	—	—
159.0	—	(A)	—	—	—

TIME (hours)	CREEP DEFORMATION (%) E.G.L. = 1.65 in.			
	STRESS = 2000 psi			
	*217-4	*217-5	*218-1	AVG.
0.1	0.06	0.18	0.18	0.14
0.2	0.30	0.24	0.24	0.26
0.5	0.64	0.33	0.48	0.48
1.0	1.12	0.60	0.73	0.82
2.0	1.70	0.97	1.09	1.28
5.0	3.70	2.73	2.97	3.13
10.0	9.03	7.76	12.48	9.76
13.4	—	—	35.88 (E)	—
13.6	31.15 (E)	—	—	—
16.6	—	35.64 (E)	—	—
18.3	—	—	(C)	—
23.1	(C)	—	—	—
41.1	—	(C)	—	—
	STRESS = 4000 psi			
	*217-2	*217-3		AVG.
0.1	1.09	0.45		0.77
0.2	1.76	0.94		1.35
0.5	3.42	2.91		3.16
1.0	8.36	7.70		8.03
1.4	17.58 (C)	18.12 (C)		17.85

LEGEND

(A) Test terminated in time indicated with no failure
(B) Test discontinued due to power failure
(C) Specimen ruptured in gage length
(E) Deformation exceeded the limits of the deformation recorder
(G) Test discontinued due to malfunction of deformation recorder
* Code numbers refer to sheet identification numbers
E.G.L. — Effective gage length

TABLE IV

CHROME-30 DEFORMATION-TIME DATA AT 2200°F

TIME (hours)	CREEP DEFORMATION ON 1-1/4 INCHES %			
		STRESS = 1000 psi		
	*221-5	*221-6	*222-1	AVG.
0.1	0.72	0.16	0.48	0.45
0.2	1.28	0.56	0.80	0.88
0.5	1.68	1.00	1.36	1.35
1.0	3.12	2.60	2.32	2.68
2.0	10.80 (A)	10.80	7.60	9.73
2.9		19.36 (A)	17.32 (A)	18.34

TIME (hours)	CREEP DEFORMATION ON 1-1/4 INCHES %			
		STRESS = 2000 psi		
	*220-3	*221-3	*221-4	AVG.
0.1	0.88	0.56	0.40	0.61
0.2	1.60	1.36	0.88	1.89
0.5	4.00	9.84	5.20	6.35
0.6			11.80 (A)	
0.7		25.76 (A)		
1.0	19.20			
1.8	32.96 (A)			

LEGEND

(A) Test terminated in time indicated with no failure

* Code numbers refer to sheet identification numbers

TABLE V

CHROME-30 STRESS RUPTURE DATA

STRESS (psi)	TEMPERATURE 1700°F	1850°F	2000°F
10000	3.0 hrs 3.8 hrs		
8000	7.0 hrs 13.0 hrs 15.2 hrs	0.65 hrs 0.66 hrs	
6000	72.9 hrs 96.8 hrs	3.20 hrs 3.30 hrs	
5000	307.3 hrs		
4000	376.2 hrs	16.5 hrs 16.7 hrs	1.40 hrs 1.40 hrs
3000		50.6 hrs 69.5 hrs	
2000			18.3 hrs 23.1 hrs 41.1 hrs

TABLE VI

STRAIN MEASUREMENT TECHNIQUES COMPARISON DATA FOR

DRAWHEAD MOVEMENT VERSUS EXTENSOMETER

STRESS = 5000 psi, TEMPERATURE = 1700°F

TIME (HRS)	TOTAL DEFORMATION	
	DRAWHEAD MOVEMENT (IN.)	EXTENSOMETER (IN./IN.)
* INITIAL DEFORMATION	0.0017	0.0017
0.10	——	0.0019
0.18	0.0036	——
0.20	——	0.0025
0.38	0.0059	——
0.50	——	0.0042
0.75	0.0086	——
1.00	——	0.0063
1.3	0.0120	——
1.9	0.0155	——
2.0	——	0.0097
3.0	——	0.0126
3.4	0.0225	——
4.0	——	0.0162
4.9	0.0290	——
5.0	——	0.0189
6.3	0.0351	——
8.0	——	0.0279

STRESS = 1000 psi, TEMPERATURE = 1800°F

TIME (HRS)	TOTAL DEFORMATION	
	DRAWHEAD MOVEMENT (IN.)	EXTENSOMETER (IN./IN.)
INITIAL DEFORMATION	0.0000	0.0000
0.10	——	0.0002
0.20	——	0.0005
0.50	——	0.0008
1.0	——	0.0011
2.0	——	0.0016
3.1	0.0040	——
5.0	——	0.0034
6.5	0.0070	——
10.0	——	0.0056
10.6	0.0091	——
13.5	0.0117	——
15.0	——	0.0079
20.0	——	0.0099
21.5	0.0197	——
23.0	——	0.0112
30.0	——	0.0150
31.5	0.0275	——
38.75	0.0328	——
40.0	——	0.0203
50.0	——	0.0258

*Initial deformation time is the time between 0 and 0.1 hour which could not be recorded

TABLE VII

EFFECTIVE GAGE LENGTH

TIME (HRS)	DEFORMATION FROM FIGURE 15		E.G.L *
	TOTAL (CURVE 1) IN.	UNIT (CURVE 2) IN./IN.	
	5000 psi, 1700°F		
0.2	0.0039	0.0025	1.56
0.5	0.0069	0.0042	1.64
1.0	0.0102	0.0063	1.62
2.0	0.0162	0.0097	1.65
3.0	0.0210	0.0127	1.65
4.0	0.0254	0.0158	1.61
	1000 psi, 1800°F		
3.5	0.0044	0.0026	1.69
5.0	0.0056	0.0034	1.65
10.0	0.0090	0.0057	1.58
20.0	0.0170	0.0100	1.70
30.0	0.0270	0.0147	1.84
40.0	0.0338	0.0203	1.66
		Avg.	1.65

* Effective gage length (E.G.L.) $= \dfrac{\text{TOTAL DEFORMATION}}{\text{UNIT DEFORMATION}}$

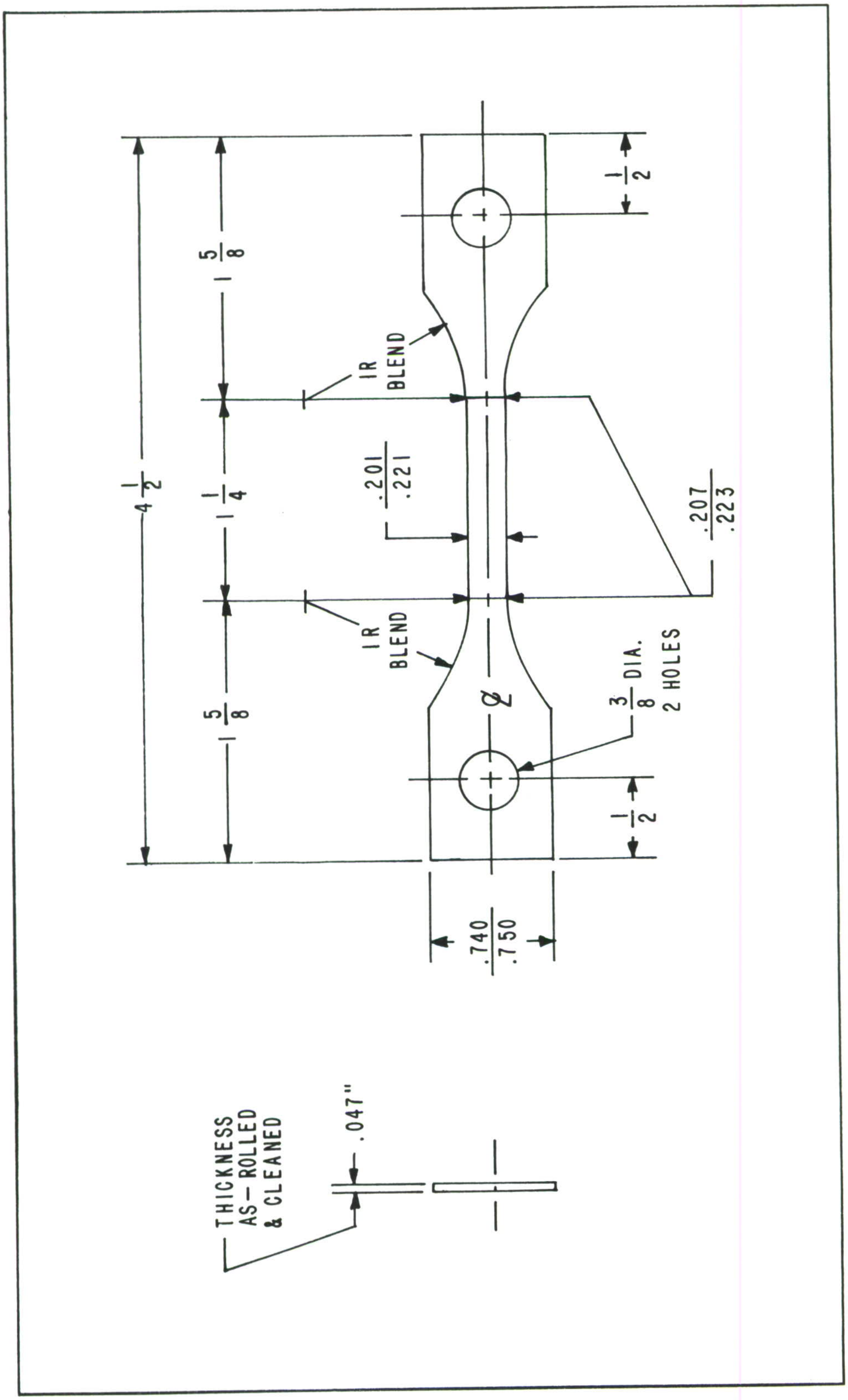

Figure 1. Creep Rupture Test Specimen

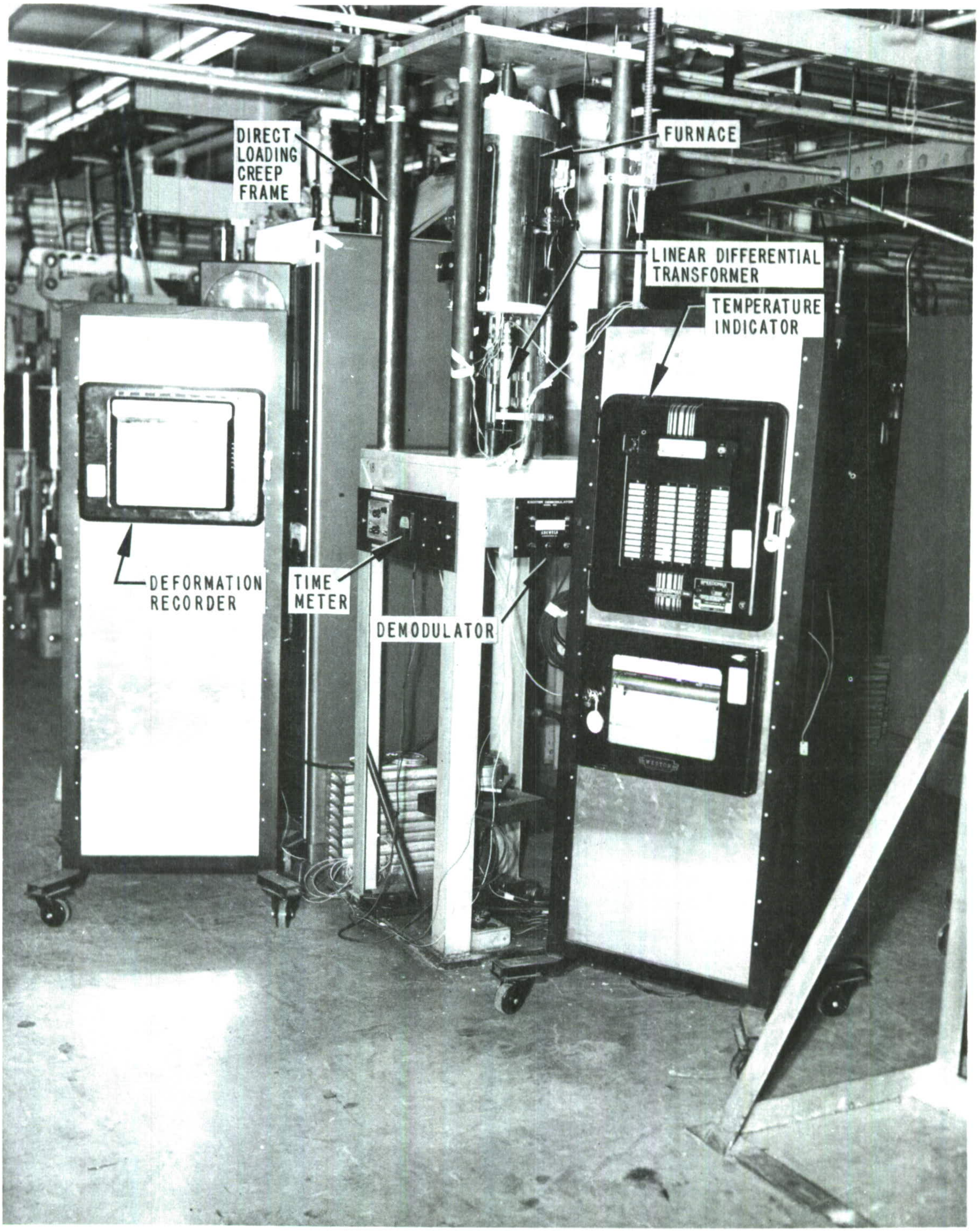

Figure 2. Test Apparatus Setup for Creep Rupture Tests

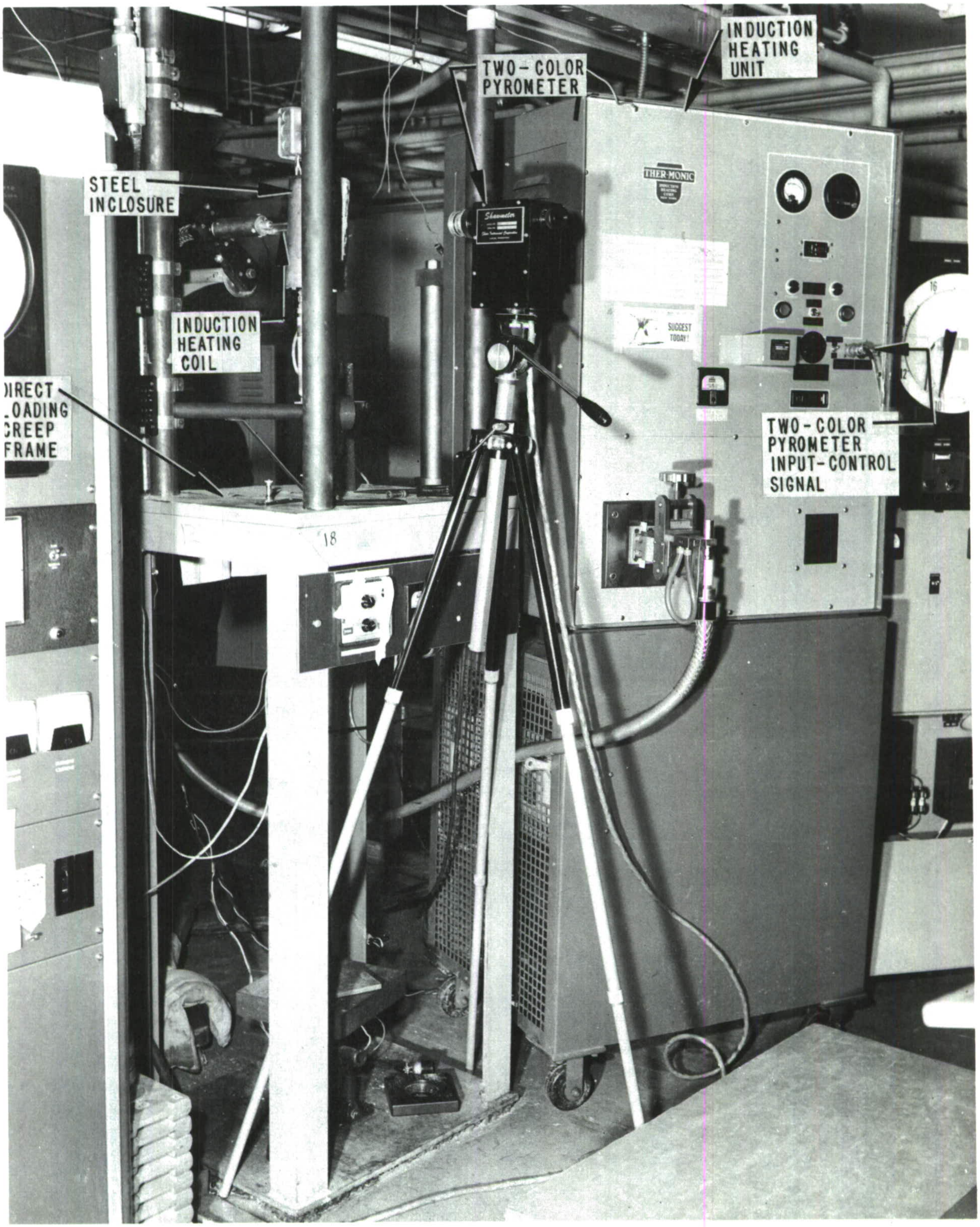

Figure 3. Trial Test Apparatus Setup for 2200°F

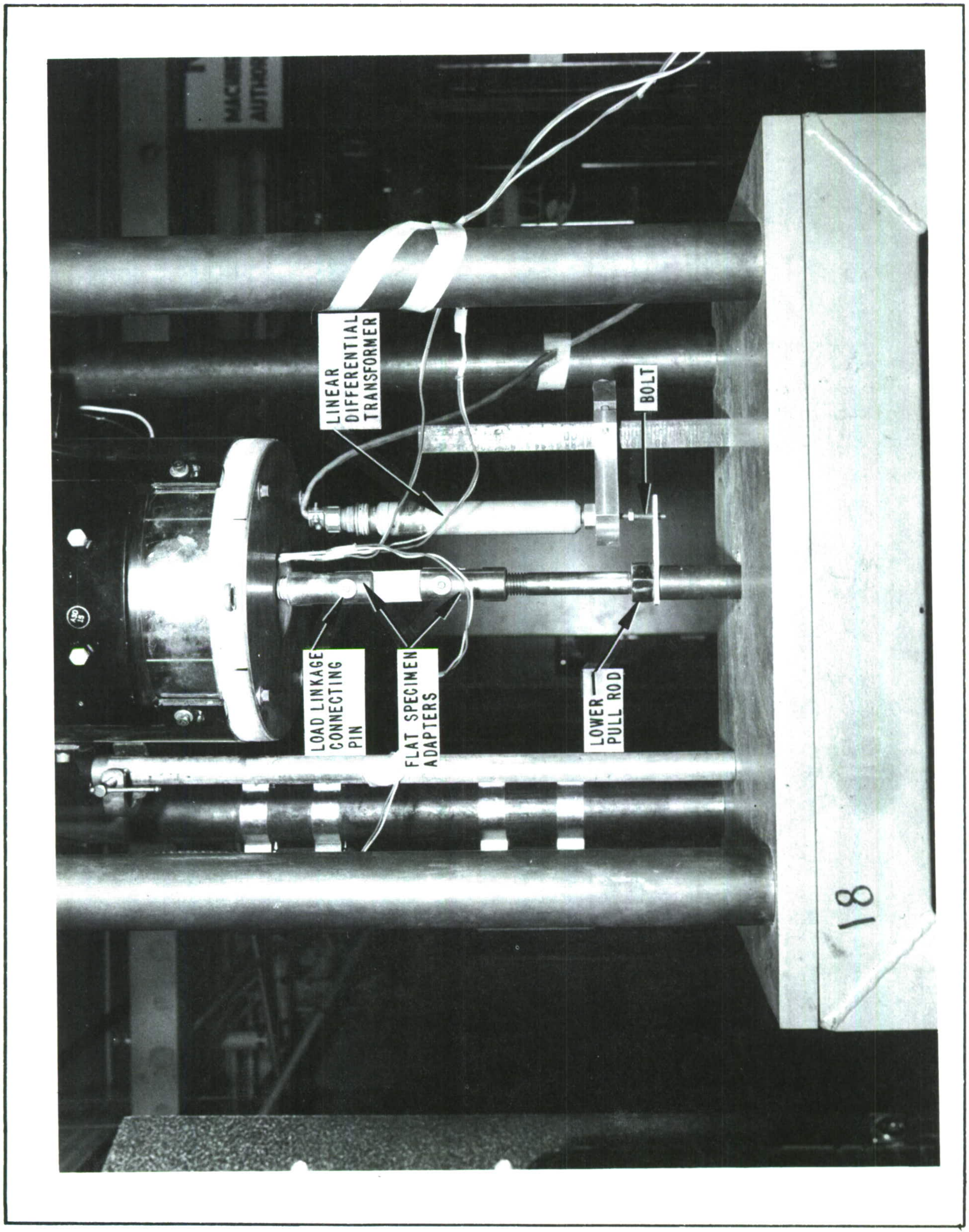

Figure 4. Strain Measuring Setup

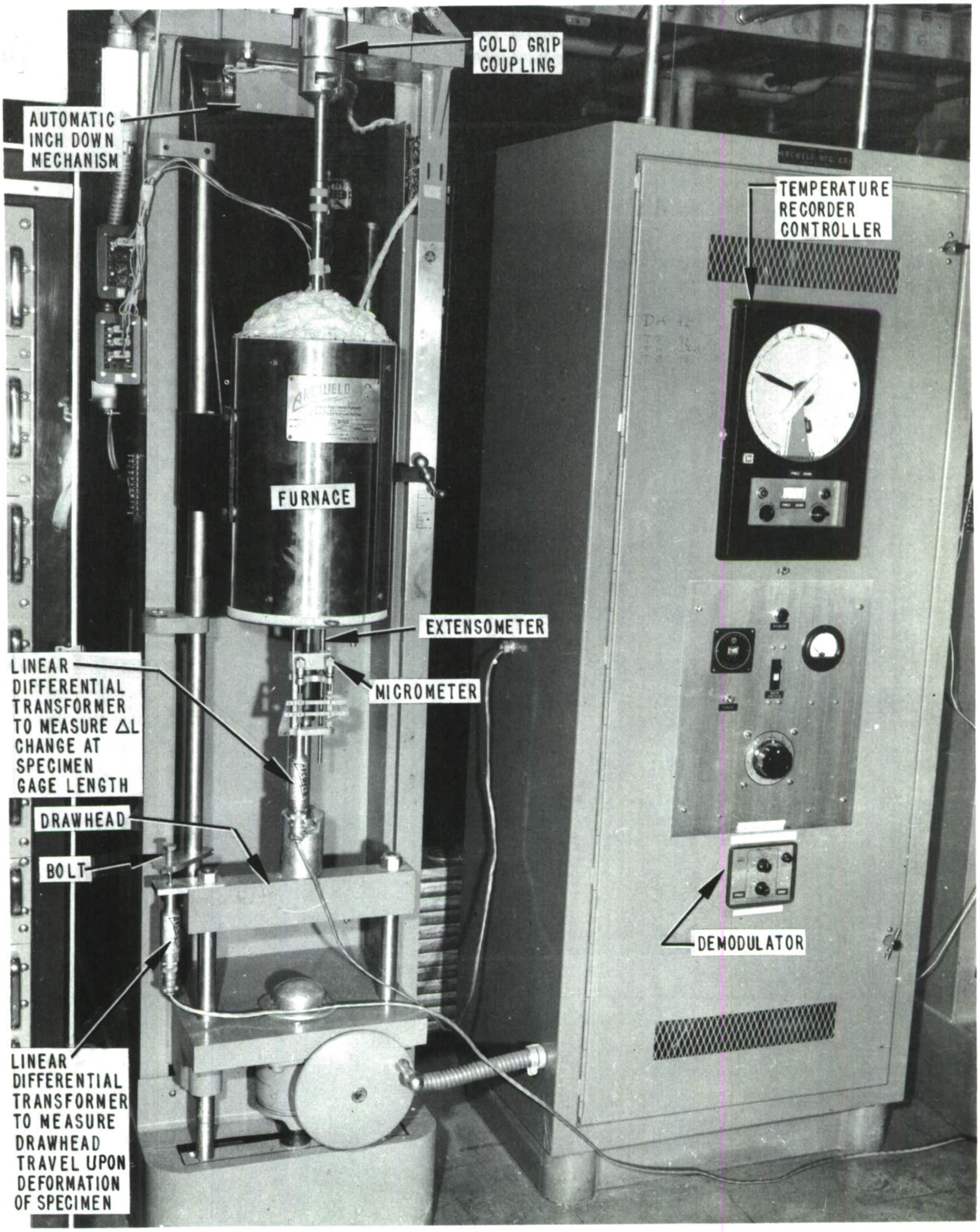

Figure 5. Test Apparatus for Correlation of Strain Measurement Techniques

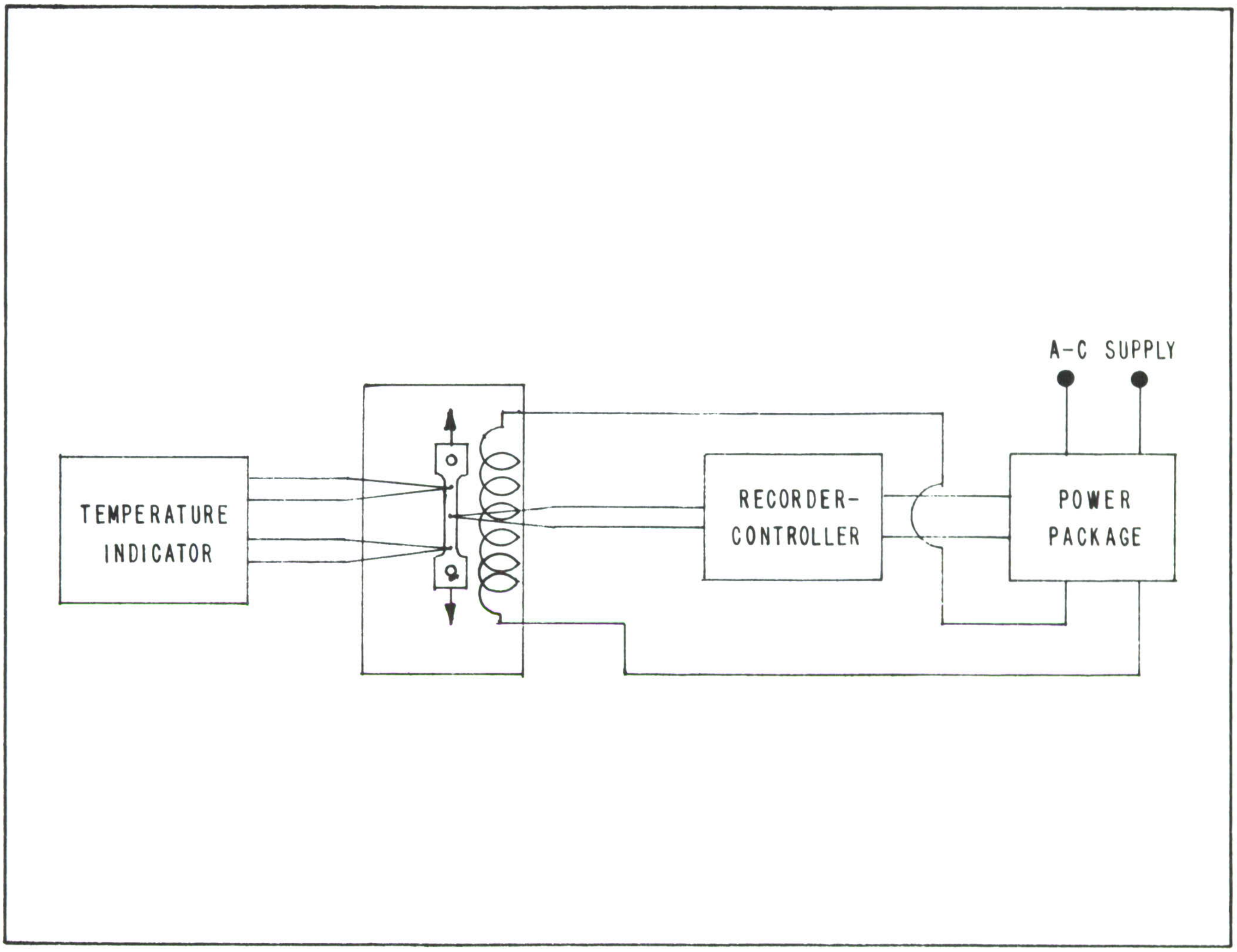

Figure 6. Schematic Diagram of Heating System

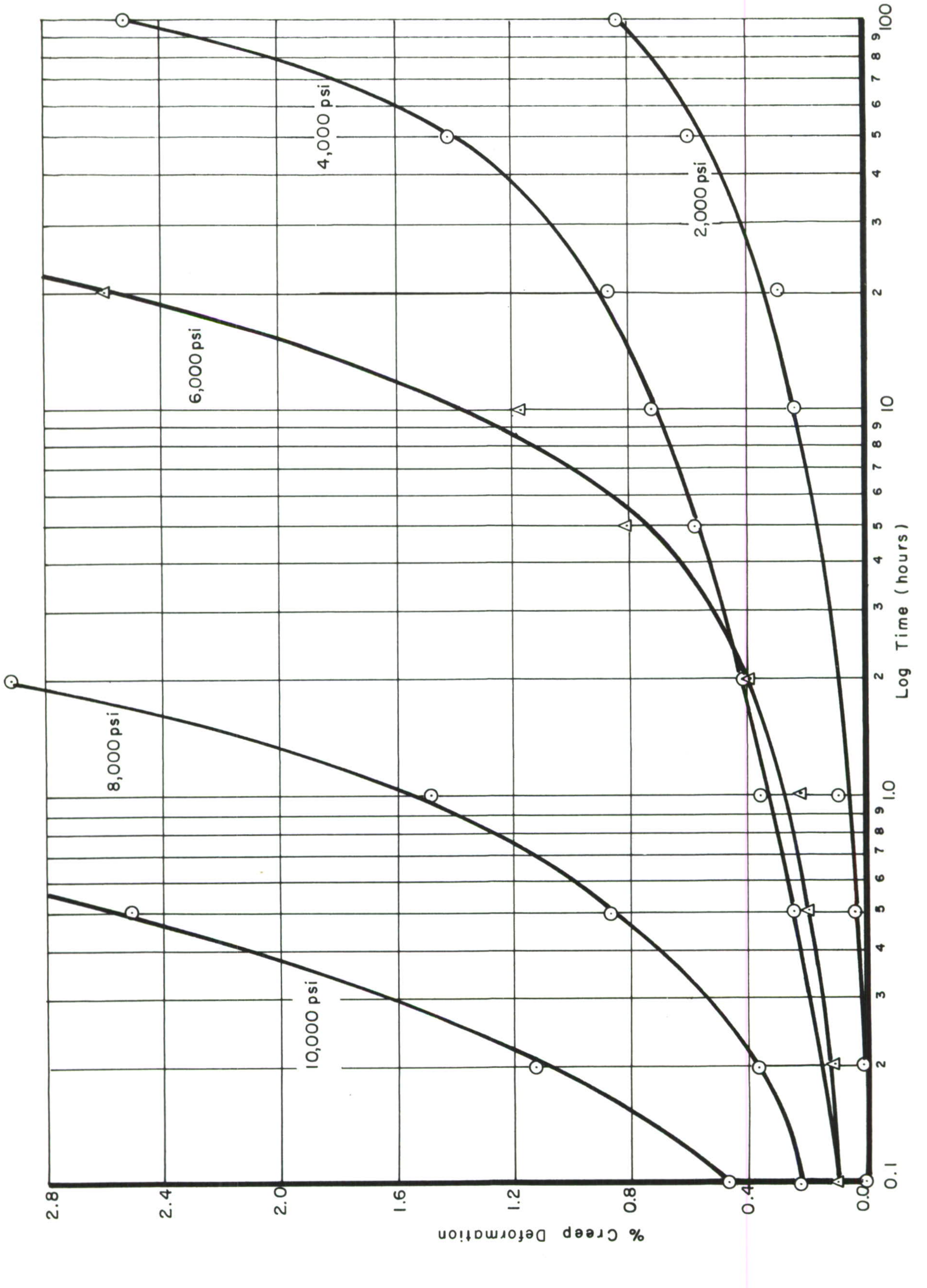

Figure 7. Creep Deformation Versus Time of Chrome-30 at 1700°F

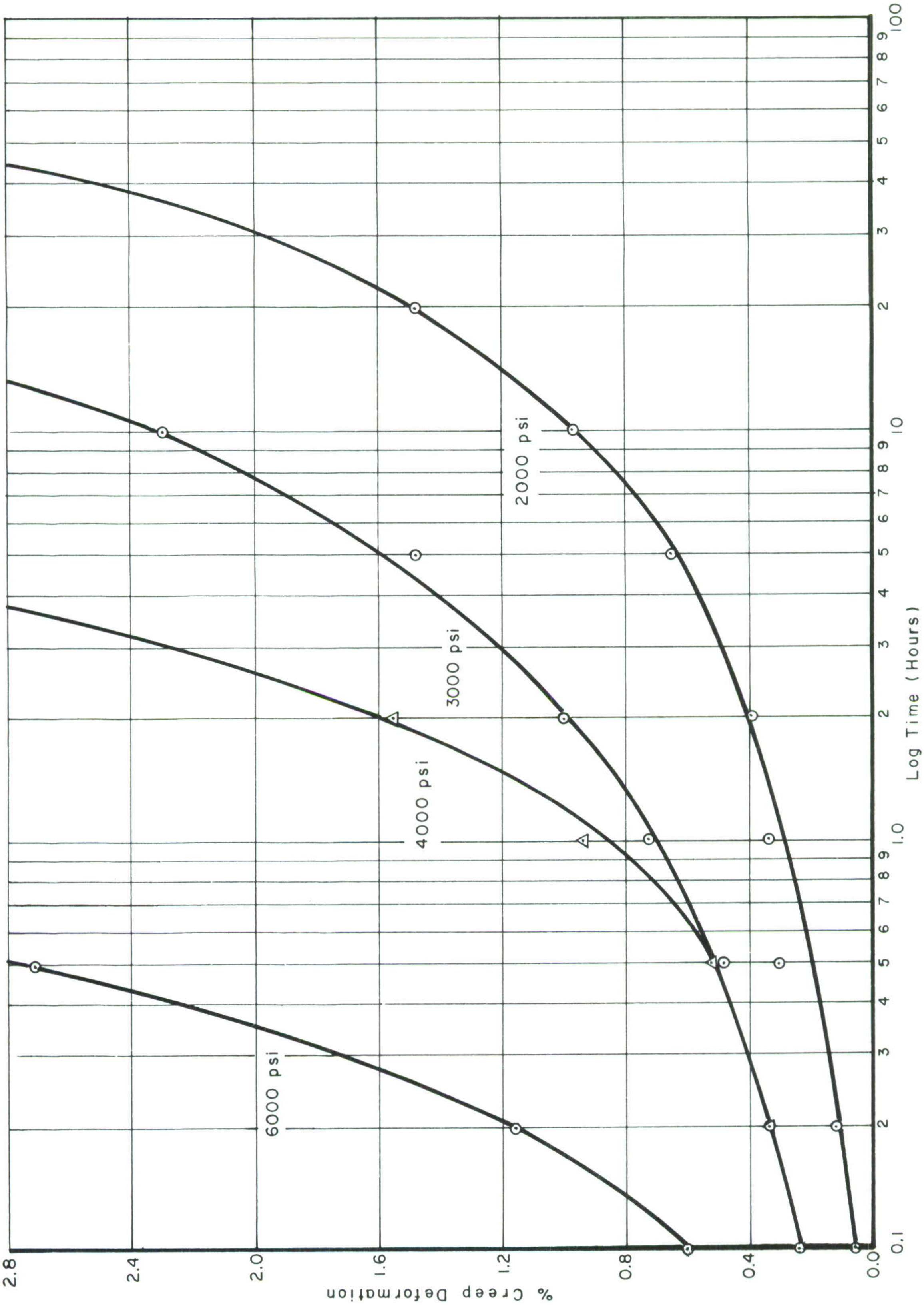

Figure 8. Creep Deformation Versus Time of Chrome-30 at 1850°F

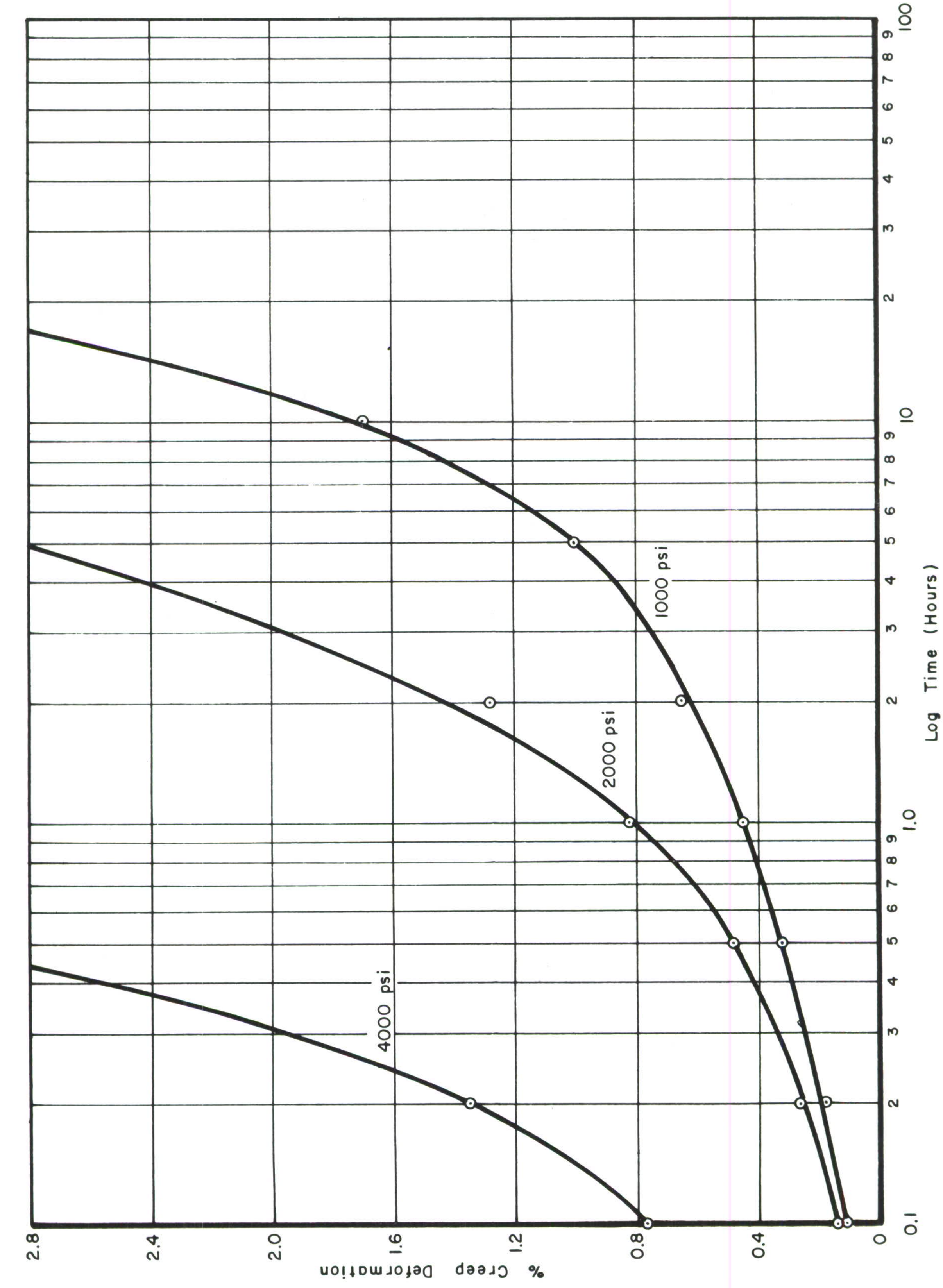

Figure 9. Creep Deformation Versus Time of Chrome-30 at 2000°F

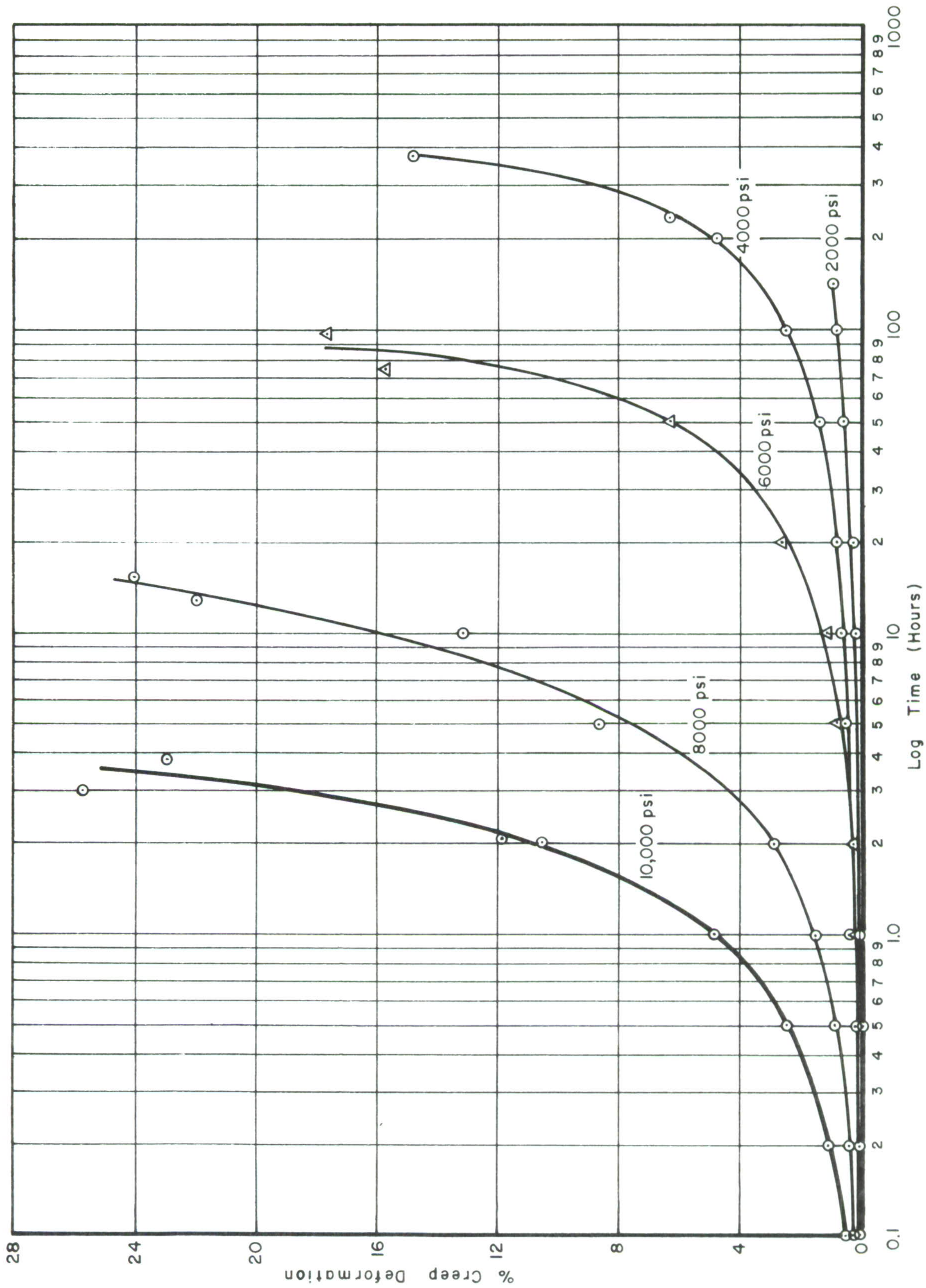

Figure 10. Creep Deformation Versus Time of Chrome-30 at 1700°F

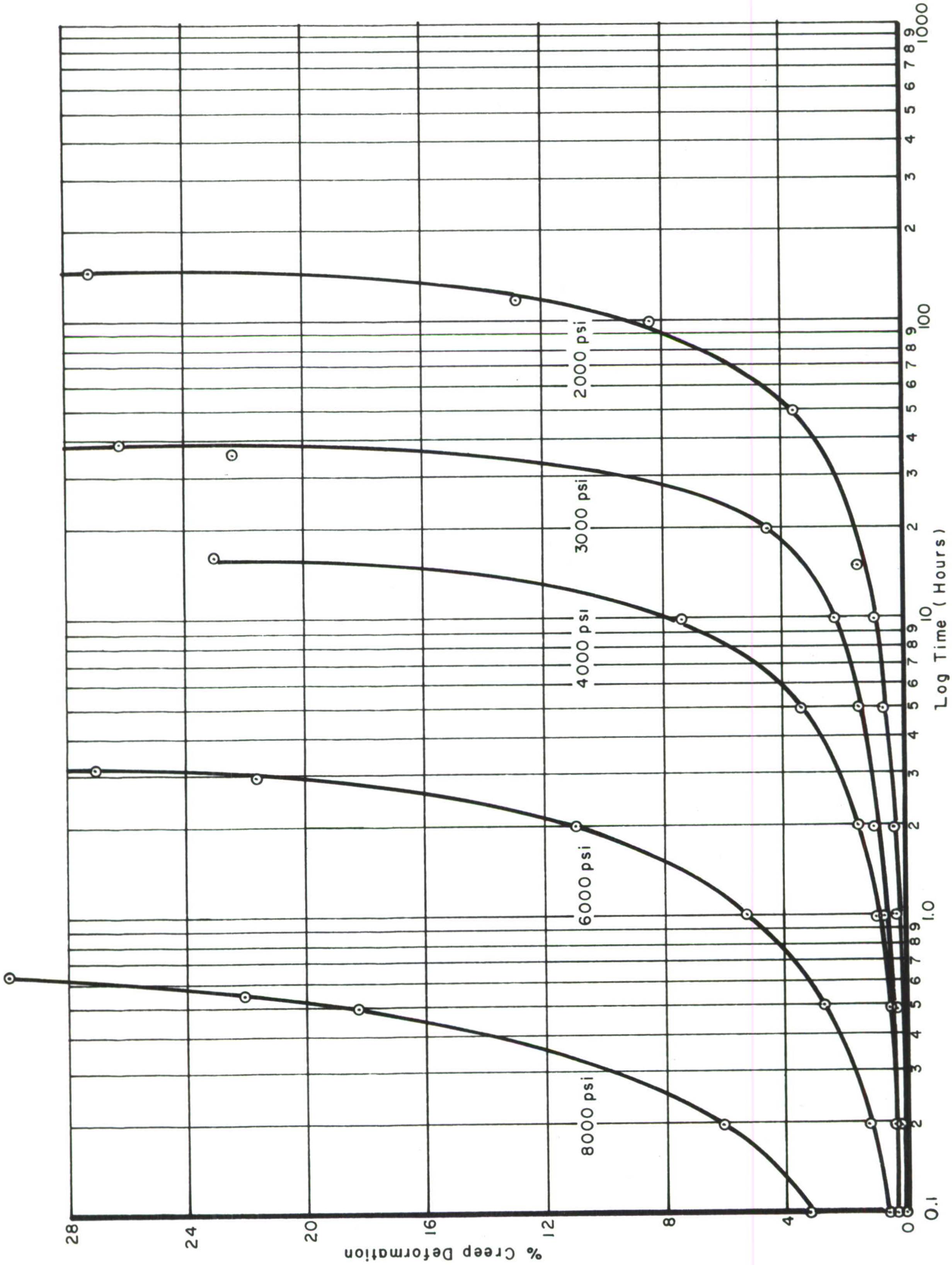

Figure 11. Creep Deformation Versus Time of Chrome-30 at 1850°F

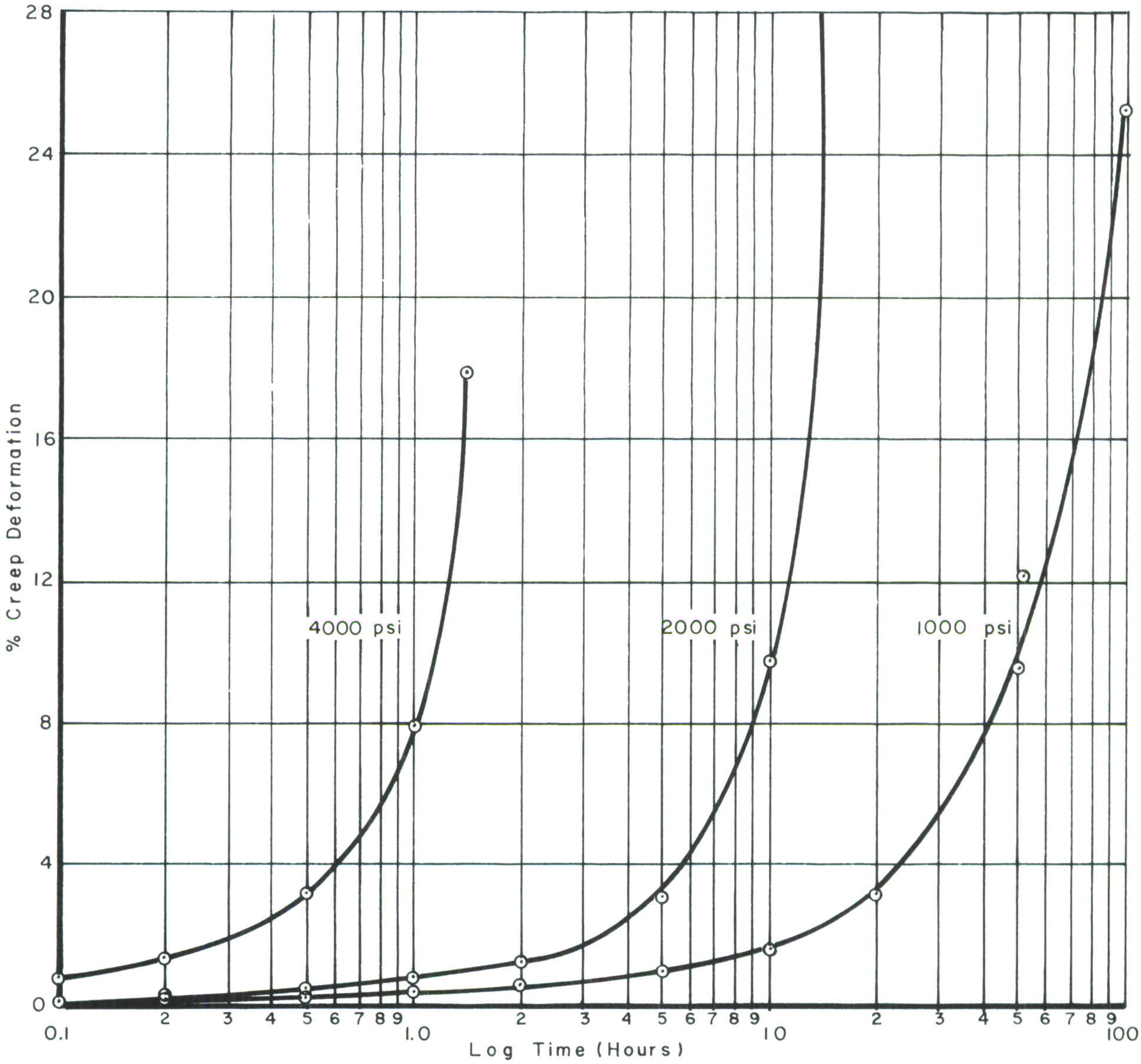

Figure 12. Creep Deformation Versus Time of Chrome-30 at 2000°F

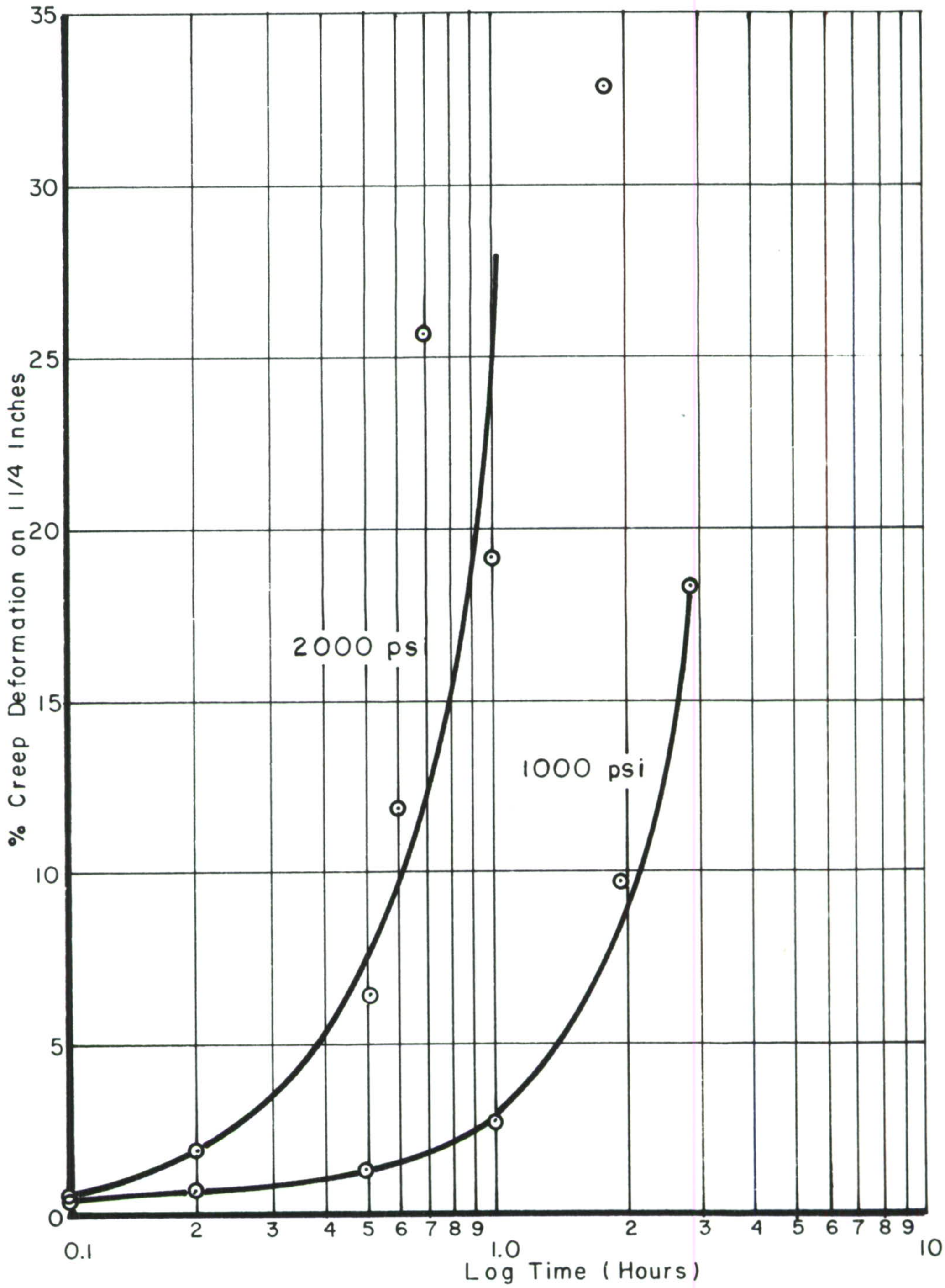

Figure 13. Creep Deformation Versus Time of Chrome-30 at 2200°F

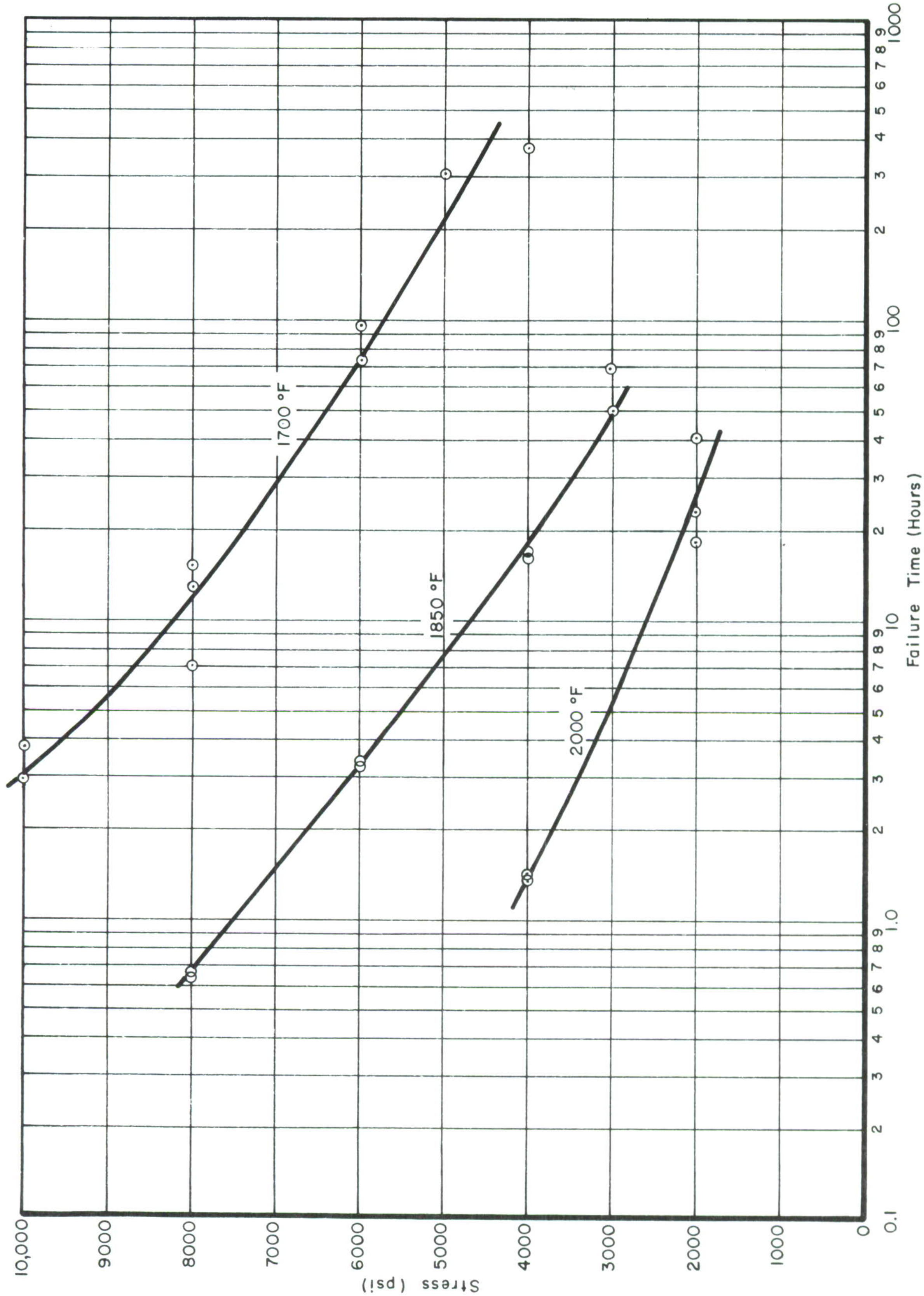

Figure 14. Stress Rupture Properties of Chrome-30

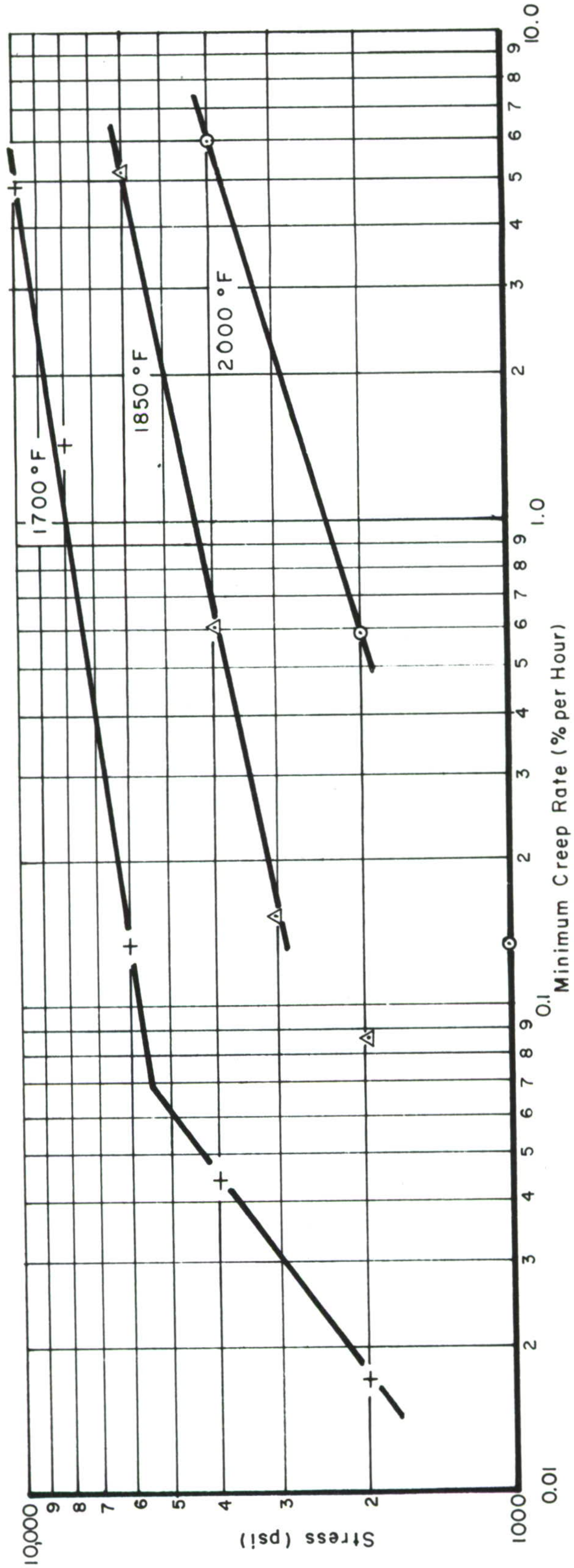

Figure 15. Stress Versus Minimum Creep Rate at Various Temperatures

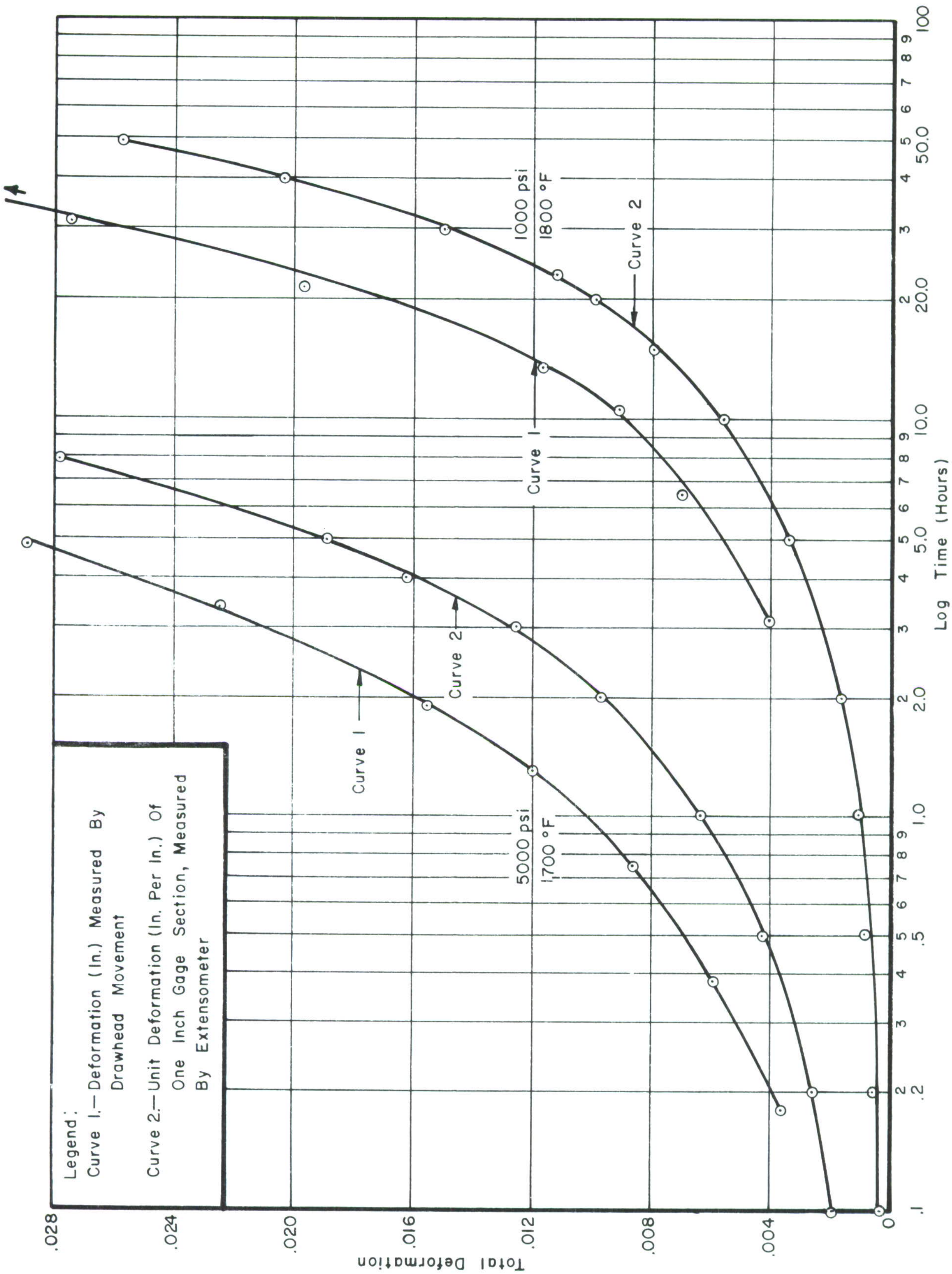

Figure 16. Creep Deformation from Drawhead Movement and Extensometer

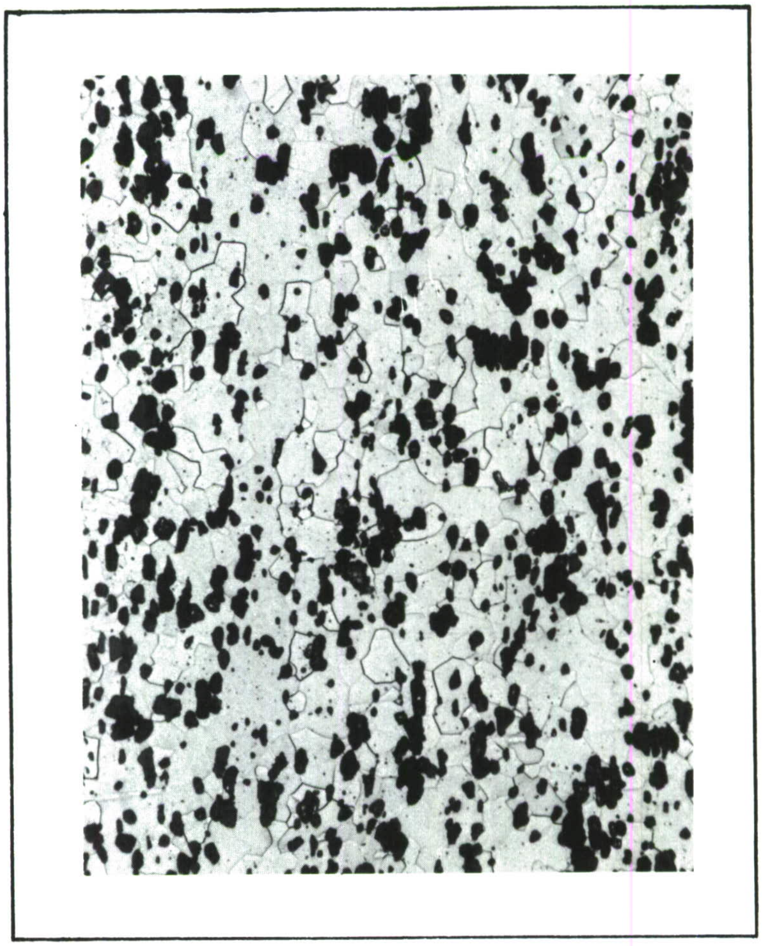

Figure 17. Photomicrograph of As-Received Sheet of Chrome-30 (250X)

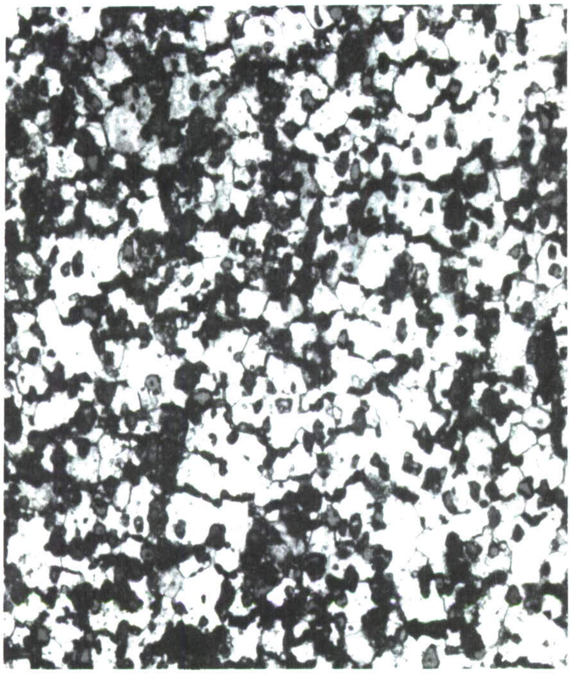

Figure 18A. Stress – 4000 psi
Failure – 376.2 hours

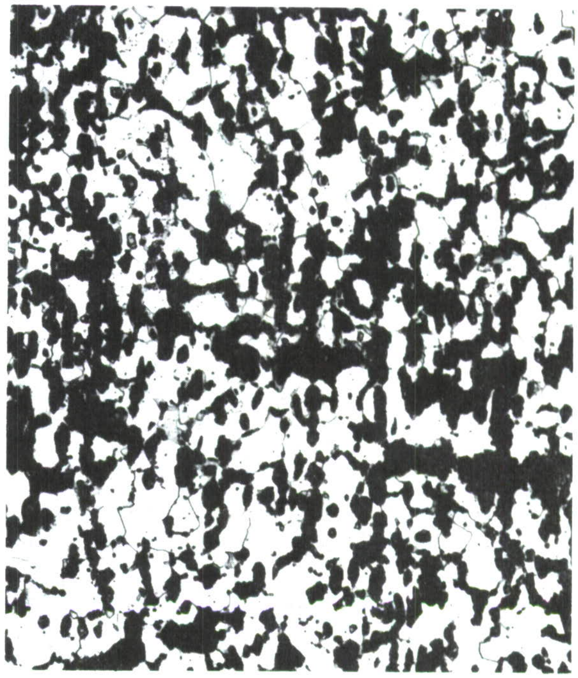

Figure 18B. Stress – 6000 psi
Failure – 96.8 hours

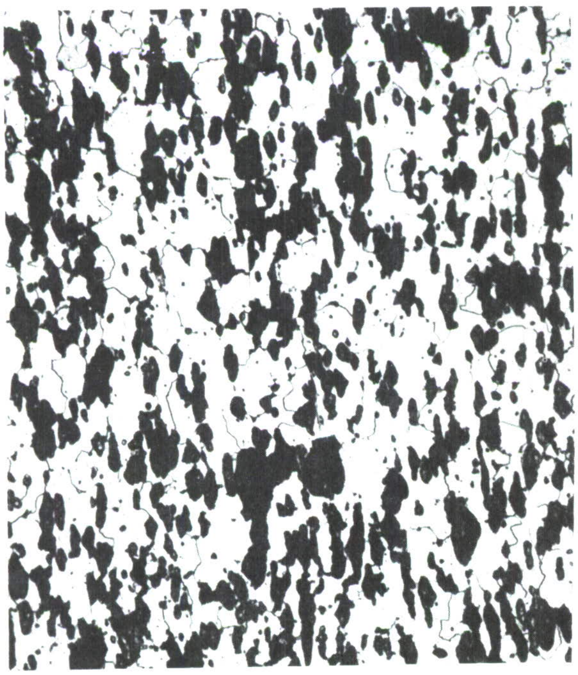

Figure 18C. Stress – 8000 psi
Failure – 7.0 hours

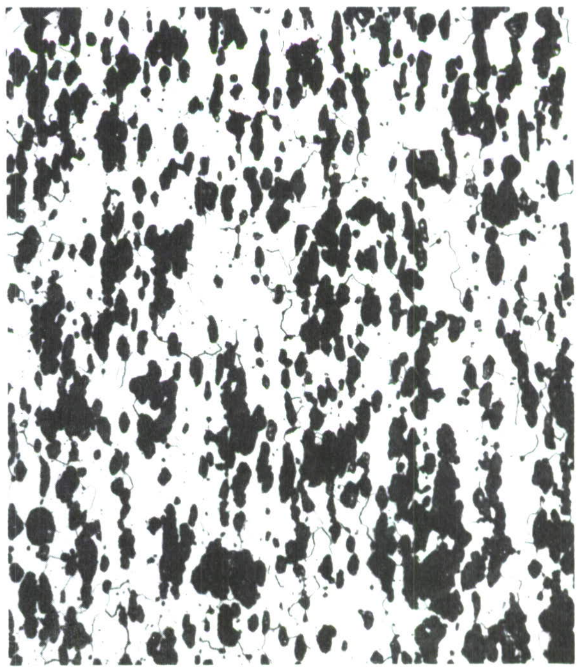

Figure 18D. Stress – 10,000 psi
Failure – 3.8 hours

Figure 18. Photomicrographs of Chrome-30 Specimens Tested at 1700°F and Indicated Stress (250X)

Figure 19A. Stress – 4000 psi
Failure – 16.7 hours

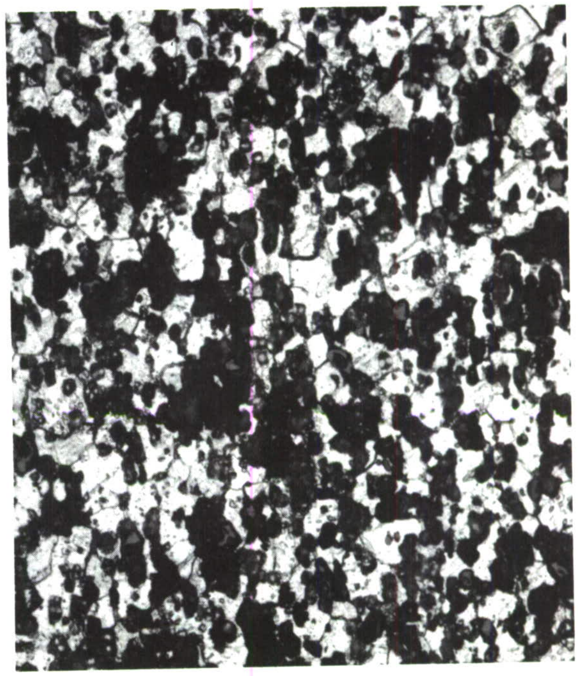

Figure 19B. Stress – 6000 psi
Failure – 3.2 hours

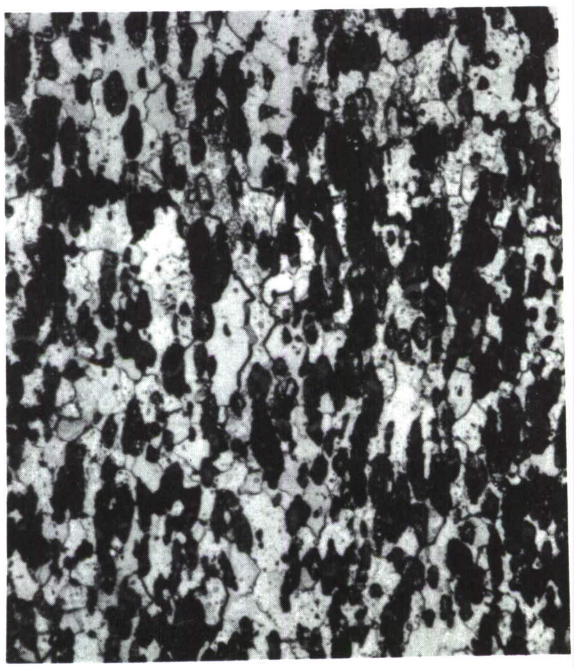

Figure 19C. Stress – 8000 psi
Failure – 0.65 hours

Figure 19. Photomicrographs of Chrome-30 Specimens Tested at 1850°F and Indicated Stress (250X)

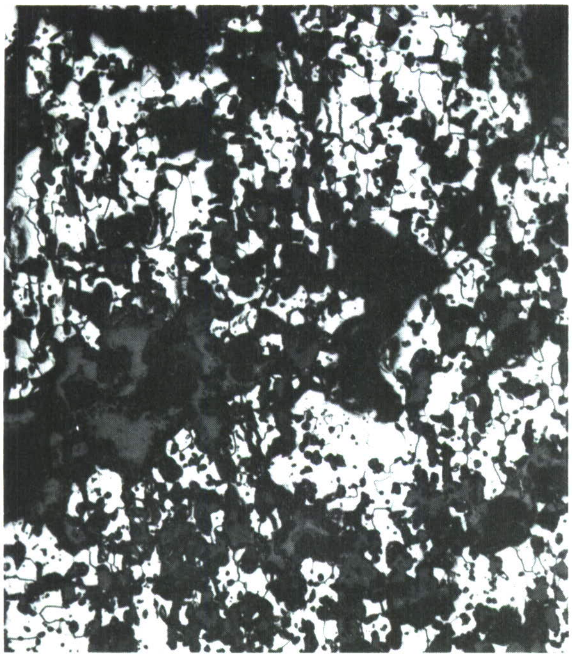

Figure 20A. Stress – 2000 psi
Failure – 23.1 hours

Figure 20B. Stress – 4000 psi
Failure – 1.4 hours

Figure 20. Photomicrographs of Chrome-30 Specimens Tested at 2000°F and Indicated Stress (250X)

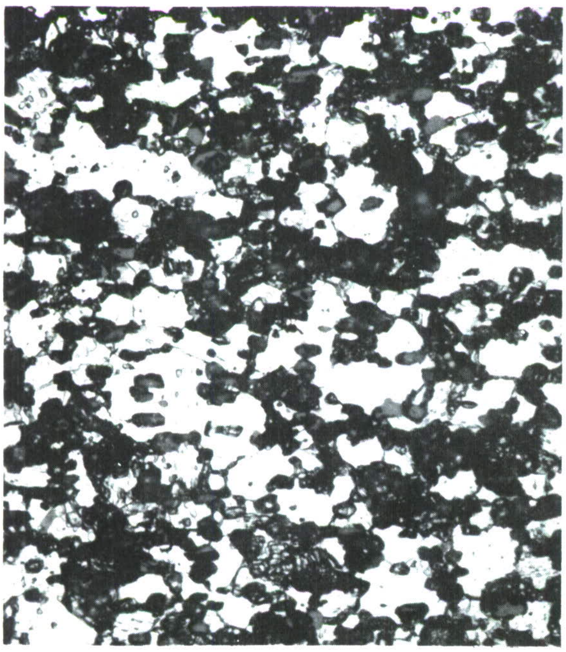

Figure 21A. Stress – 1000 psi
Tests discontinued prior to failure.

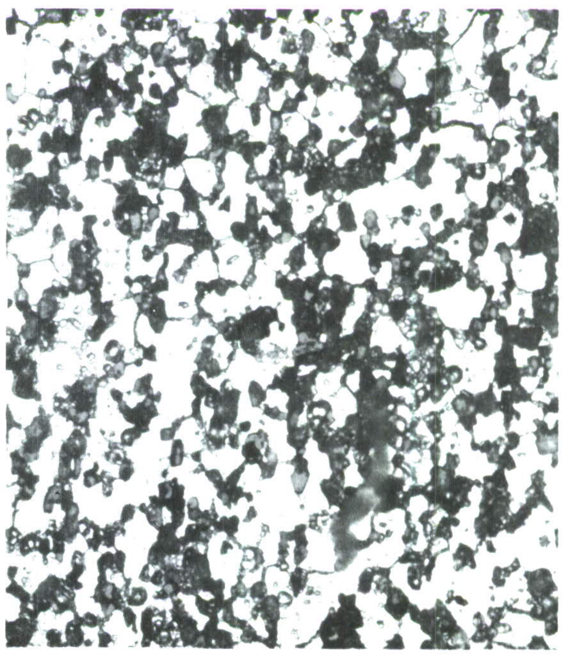

Figure 21B. Stress – 2000 psi
Tests discontinued prior to failure.

Figure 21. Photomicrographs of Chrome-30 Specimens Tested at 2200°F and Indicated Stress (250X)

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1. ORIGINATING ACTIVITY *(Corporate author)* Materials Information Branch Materials Applications Division Air Force Materials Laboratory	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

Creep Properties and Creep Measurement Techniques for a Chromium-Magnesium Oxide Composite Up to 2200°F in Air

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Final Report - March 1963 - July 1964

5. AUTHOR(S) *(Last name, first name, initial)*

Davis, Sidney O.

Watson, David C.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
June 1966	36	6

8a. CONTRACT OR GRANT NO. b. PROJECT NO. 7381 c. Task No. 738106 d.	9a. ORIGINATOR'S REPORT NUMBER(S) AFML-TR-66-102 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

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13. ABSTRACT

A test program was conducted to obtain creep rupture properties of a chromium-magnesium oxide composite alloy, Chrome-30 (93.5 percent chromium, 0.5 percent titanium, 6.0 percent magnesium oxide), at elevated temperature in an air environment. Four series of creep rupture tests were conducted at temperatures of 1700°, 1850°, 2000°, and 2200°F with stresses applied ranging from 1000 to 10,000 psi using a constant load machine. The material was in the form of 0.047 inch thick sheet.

In addition to the creep rupture properties, a detailed description of the test equipment and testing procedure is presented. Photomicrographs are included to describe the general microstructure.

Also included is a discussion of the correlation of total deformation versus time at elevated temperatures using two measuring methods, drawhead movement versus extensometer measurements. The test data revealed that there can be as much as 65 percent error in total deformation reported when measuring creep using drawhead movement of the creep frame instead of using an extensometer fastened firmly to the gage section.

DD FORM 1 JAN 64 1473

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Creep Rupture Properties Chromium-magnesium Oxide Composite Chrome-30 Creep Measurement Techniques						

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